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Pediatric Obesity/Obesity Prevention

What childhood obesity prevention programmes work? A systematic review and meta-analysis

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Summary

Previous reviews of childhood obesity prevention have focused largely on schools and findings have been inconsistent. Funded by the US Agency for Healthcare Research and Quality (AHRQ) and the National Institutes of Health, we systematically evaluated the effectiveness of childhood obesity prevention programmes conducted in high-income countries and implemented in various settings. We searched MEDLINE®, Embase, PsycINFO, CINAHL®, ClinicalTrials.gov and the Cochrane Library from inception through 22 April 2013 for relevant studies, including randomized controlled trials, quasi-experimental studies and natural experiments, targeting diet, physical activity or both, and conducted in children aged 2–18 in high-income countries. Two reviewers independently abstracted the data. The strength of evidence (SOE) supporting interventions was graded for each study setting (e.g. home, school). Meta-analyses were performed on studies judged sufficiently similar and appropriate to pool using random effect models. This paper reported our findings on various adiposity-related outcomes. We identified 147 articles (139 intervention studies) of which 115 studies were primarily school based, although other settings could have been involved. Most were conducted in the United States and within the past decade. SOE was high for physical activity-only interventions delivered in schools with home involvement or combined diet–physical activity interventions delivered in schools with both home and community components. SOE was moderate for school-based interventions targeting either diet or physical activity, combined interventions delivered in schools with home or community components or combined interventions delivered in the community with a school component. SOE was low for combined interventions in childcare or home settings. Evidence was insufficient for other interventions. In conclusion, at least moderately strong evidence supports the effectiveness of school-based interventions for preventing childhood obesity. More research is needed to evaluate programmes in other settings or of other design types, especially environmental, policy and consumer health informatics-oriented interventions.

Keywords: Childhood, obesity, prevention, systematic review.

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Introduction

Childhood obesity persists as a serious threat to public health worldwide (1–5). In the United States, over two-thirds of adults and one-third of children are overweight or obese. Childhood obesity has many health consequences (6,7). Obesity is the result of biological, behavioural, social, environmental and economic factors and the complex interactions between them, which can produce a positive energy balance (8,9). Several leading health organizations and expert panels, including the World Health Organization (10) and Institute of Medicine (IOM), have recommended comprehensive interventions to combat childhood obesity (11,12).

Some prior systematic reviews have summarized findings of childhood obesity prevention studies (13–16); however, findings have been mixed and often limited either by the length of follow-up, exclusively focusing on a specific intervention setting (e.g. school) or certain outcomes (e.g. body mass index [BMI]), or by including only a small number of studies.

The present study aimed to systematically evaluate the effectiveness of all childhood obesity prevention programmes implemented in various settings or designs (e.g. school, home, primary care, childcare, community, consumer health informatics [CHI]) conducted in high-income countries. Our original systematic review that served as the basis for the present study was funded by the Agency for Healthcare Research and Quality (AHRQ) of the US Department of Health and Human Services. Our full 835-page research report for AHRQ includes a literature review for six intervention settings and designs and was published in June 2013 (17). (For the present study, we conducted a new literature search for studies published after the completion of our AHRQ report and included them in analyses.) We reviewed studies implemented in any setting (or design) that tested obesity prevention interventions targeting diet, physical activity (PA) or a combination of both behaviours.

In our original AHRQ-funded study, we assessed various key outcomes including certain adiposity-related measures, behaviours such as dietary consumption, PA and sedentary behaviours, and some other health markers such as blood lipid levels and blood pressure. The present study focuses on the effects of the interventions on adiposity outcomes and aims to provide the variety of readers (e.g. researchers, health professionals and policy makers) a refined, comprehensive review of findings to help guide future interventions and research, particularly in children of high-income countries.

The present study provides new knowledge and possesses additional features and strengths compared with previous reviews on childhood obesity prevention including our full AHRQ report published in June 2013. This study is more encompassing as it included studies set in various settings, it assessed a wide variety of outcome measures and it followed a rigorous protocol – that required of AHRQ-funded comparative effectiveness reviews. More details on our research methods and findings can be found in our full AHRQ report (17).

Methods

Our large research team consisted of epidemiologists, clinicians, nutritionists, biostatisticians and health policy researchers from multiple institutions. We followed standardized procedures developed by the AHRQ Effective Healthcare Program and benefited from the input of experts in the field, with the AHRQ and other stakeholders, throughout the project's stages. For example, we developed our key questions (KQs) with the input of a key informant panel that included experts in childhood nutrition policy, academic clinicians treating obese children, representatives from public school systems, parents of obese children, representatives from professional societies focusing on nutrition and obesity, and AHRQ staff. In addition, we also formed a technical expert panel of leading experts and other stakeholders in the field, which provided input on the development of our study protocol. Our full report was reviewed by both experts and the public and improvements were made based on their feedback. Additional details are provided in the full AHRQ manuscript (17).

Search strategy and selection criteria

We searched MEDLINE®, EMBASE®, PsycINFO, CINAHL® and the Cochrane Library from inception through 22 April 2013. We developed a search strategy based on medical subject heading (MeSH®) terms and the text of key articles we had identified *a priori*. We reviewed the reference lists of all included articles and all pertinent review articles to identify articles the database searches may have missed. We uploaded all articles into DistillerSR (Evidence Partners, Ottawa, Ontario, Canada), a web-based software application developed for systematic review and data management. We also conducted a grey literature search in ClinicalTrials.gov to identify relevant unpublished research through 23 July 2012.

We identified studies conducted in high-income countries, defined as those with a very high human development index (18), that evaluated interventions to prevent obesity (or 'excessive weight gain') in children aged 2–18 years. We only included randomized controlled trials (RCTs), quasi-experimental studies and natural experiments that reported intervention effects on adiposity-related outcomes. The studies also needed to follow participants for at least 1 year from baseline measures, or for six or more months in school-based interventions (considering the length of the

school year). Studies targeting only overweight or obese children or children with medical conditions (e.g. diabetes) were excluded.

Data extraction

Two independent reviewers conducted title, abstract and full article reviews to assess inclusion eligibility. Standardized forms were used for data abstraction. Each article was double reviewed during this phase: the second reviewer confirmed or corrected the first reviewer's data abstractions for completeness and accuracy. Information on the study characteristics, subjects, eligibility criteria, intervention components, outcome measures and method of ascertainment regarding body weight status were abstracted.

Primary adiposity-related outcomes of interest were BMI, BMI *z*-score, BMI percentile, waist circumference (WC), percent body fat (%BF), skin-fold thickness and prevalence of overweight or obesity. Secondary outcomes (not reported on in this paper) were intermediate behavioural outcomes (i.e. dietary intakes, PA and sedentary behaviours) and obesity-related clinical outcomes (e.g. blood pressure and blood lipid levels).

Quality (risk of bias) assessment of individual studies

Two independent reviewers used the Downs and Black Checklist for Measuring Quality, summarized here, to assess risk of study bias (ROB) for each included study (19): (i) low ROB: when a study fulfilled all of the following: clearly stated the objective, described the main outcomes, described the characteristics of the enrolled subjects, clearly described the interventions, described the main findings, randomized the subjects to the intervention group, concealed the intervention assignment until recruitment was complete and had at least partially described the distributions of (potential) confounders in each treatment group; (ii) moderate ROB: if a study did not fulfil one of the aforementioned items, or if such could not be verified and (iii) high ROB: if a study did not fulfil more than one of the aforementioned items.

Data synthesis

For each intervention setting, we created a set of detailed evidence tables containing the information extracted from all eligible studies fitting that setting (or design). We aggregated the studies by the primary setting where the interventions took place. Within each setting, we grouped the interventions into three groups by strategy: (i) 'diet-only interventions', those who aimed to alter dietary intake only; (ii) 'PA-only interventions', those who aimed to increase PA and/or reduce sedentary activity only and (iii) 'diet–PA combined interventions', those who targeted both diet and PA for change.

When more than three comparable studies were available for a given intervention strategy and setting(s), we conducted meta-analyses using STATA (version 11.0; Stata Corp., College Station, TX, USA). We used random-effect models applying the DerSimonian and Laird approach due to the heterogeneity present among studies (20). A study was not included in the meta-analysis if it (i) was not an RCT; (ii) induced substantial heterogeneity when included in the analysis (i.e. I^2 >50% or *P*-value <0.1 from chi-square tests assessing the heterogeneity of effect sizes across interventions) or (iii) did not report sufficient data.

Strength of the body of evidence

We graded the quantity, quality and consistency of the best available evidence of interventions for each setting by adapting an evidence-grading scheme recommended in the Methods Guide for Conducting Comparative Effectiveness Reviews (21). We assigned grades for all adiposity-related outcomes by first constructing a hierarchy of outcomes. Using the hierarchy, each study contributed only one (the highest ranked) adiposity-related measure for grading. We considered four domains in our evaluation of strength of evidence (SOE): ROB, direction of the body of evidence, consistency of outcomes across studies and precision of the pooled estimate or individual study estimates.

We determined an overall ROB for each setting and intervention target (i.e. diet, PA or both) combination based on where most studies in their respective groupings fell. We decided that all of the included studies provided evidence of a direct effect. We considered the body of studies to be consistent in direction if more than 70% of the studies in a grouping had an effect in the same direction. We considered an individual study to be precise if the results for the given outcome were significant ($P < 0.05$) or if estimates had narrow confidence intervals (CI) that excluded the null. If more than 70% of the individual studies were precise, we considered the body of evidence to be precise.

SOE was classified into four categories: (i) 'high', indicating high confidence that the evidence reflects the true effect and further research is very unlikely to change our confidence in the estimate of the effect; (ii) 'moderate', indicating moderate confidence and further research may change our confidence and the estimate; (iii) 'low', meaning low confidence and further research is likely to change our confidence and the estimate and (iv) 'insufficient', reflecting that either a body of evidence is unavailable or there was only one study for this setting and it had moderate or high ROB.

Results

Results of the literature search and intervention studies

We identified 42,221 unique citations, which resulted in 7,392 abstracts and, later, 677 articles after screening. A final 139 intervention studies described in 147 articles (21.7%) met our inclusion criteria (Fig. 1). This included 115 studies that assessed school-based interventions, six home-based interventions, three primary care-based interventions, five child care-based interventions and 10 community-based interventions. Seven studies were interventions using CHI, which we combined and described under other intervention settings (see Fig. 1, Appendix A, Table 1). None of the unpublished studies met our selection criteria.

The majority of the 139 studies (104 or 75%) evaluated diet–PA combined interventions, 28 evaluated PA-only interventions and seven evaluated diet-only interventions (Table 2). As described in detail below, 76 of the 115 studies (66%) evaluating school-based interventions showed favourable intervention effects on adiposity-related outcomes, but only 42 of them (36%) were statistically significant. None of the home-based studies reported statistically significant favourable results. One out of three (33%) primary care-based studies, two out of five (40%) child care-based studies and five out of 10 (50%) community-based studies reported significant and favourable effects on adiposity-related outcomes (Table 2). Multi-setting studies had statistically significant favourable results more often than single-setting studies (44 vs. 35%) (Table 3).

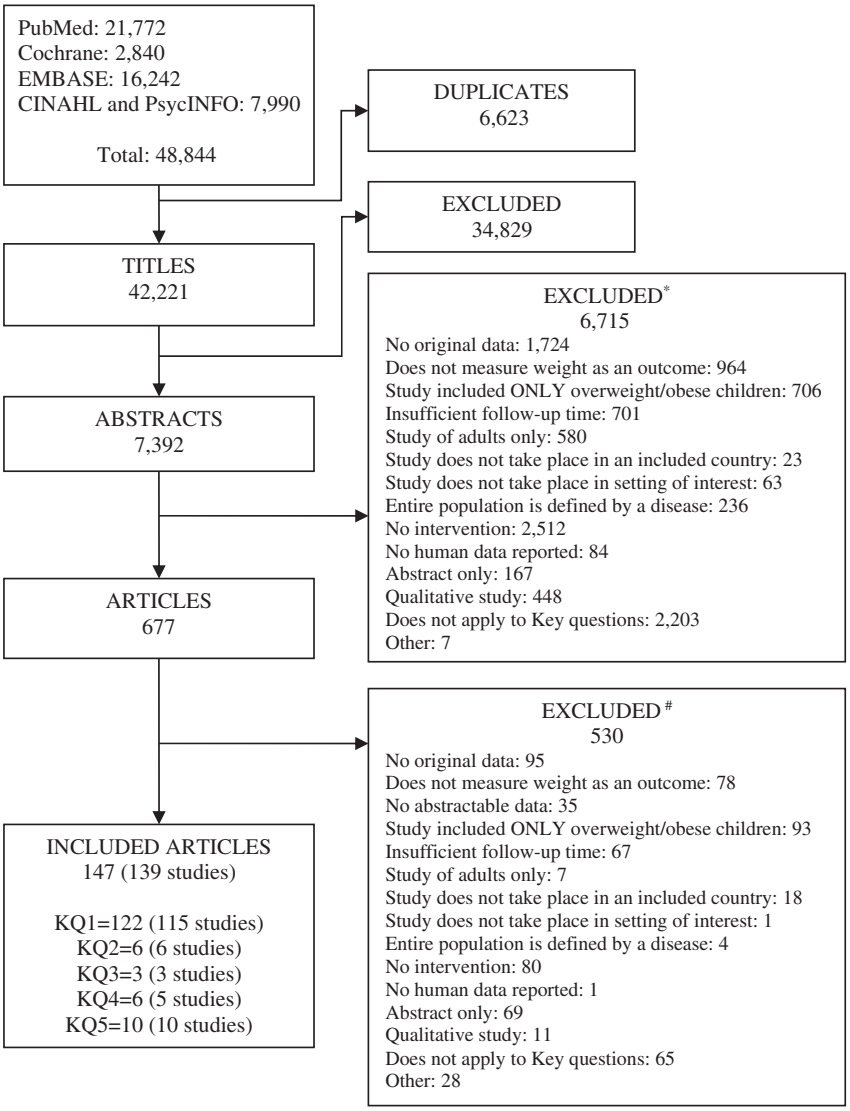

Figure 1 Results of the literature search on childhood obesity prevention studies/interventions in high-income countries. *Sum of excluded abstracts exceeds 6,175 because reviewers were not required to agree on reasons for exclusion. #Sum of excluded abstracts exceeds 530 because reviewers were not required to agree on reasons for exclusion. The key questions (KQs) of this review were organized by study setting/design as follows: What is the comparative effectiveness of school-based interventions (KQ1), home-based interventions (KQ2), primary care-based interventions (KQ3), childcare setting-based interventions (KQ4) and community-based interventions (KQ5) for the prevention of obesity or overweight in children? Note that our original Agency for Healthcare Research and Quality study also included KQ6 'What is the comparative effectiveness of consumer health informatics applications for the prevention of obesity or overweight in children?' and KQ7 'What is the comparative effectiveness of multi-setting interventions for the prevention of obesity or overweight in children?', but, in the present study, the interventions previously classified under these headings were grouped into KQ1 or KQ2 based on if the intervention was primarily school or home based, or another KQ based on the key intervention setting. We merged KQ6 and KQ7 with the other KQ groups to help simplify the presentation of information and because of the relatively small number of studies originally grouped into KQ6 and KQ7.

Table 1 Summary of the results of the 139 childhood obesity prevention studies on adiposity-related outcomes*†

Setting	Type of intervention, number of studies	Years of publication	Enrolled participants	Studies with low/moderate/high risk of bias (*n*)	% with favourable outcome ($P < 0.05$)	% with favourable outcome ($P < 0.05$ not necessary)	Risk of bias	Consistency	Precision	Strength of evidence
School based										
School only	D, 3	1995–2012	2,423	1/2/0	67	100	Moderate	Consistent	Imprecise	Moderate
	PA, 18	1993–2013	10,488	0/14/4	22	72	Moderate	Consistent	Imprecise	Moderate
	C, 40	1985–2013	47,665	2/29/9	44	53	Moderate	Inconsistent	Imprecise	Insufficient
School and home	D, 1	1986	1,321	0/1/0	100	100	Moderate	NA	Precise	Insufficient
	PA, 3	1999–2010	1,654	1/2/0	100	100	Moderate	Consistent	Precise	High
	C, 28	1991–2013	33,297	2/20/6	36	79	Moderate	Consistent	Imprecise	Moderate
School, home and community	PA, 1	2010	2,829	0/1/0	0	0	Moderate	NA	Imprecise	Insufficient
	C, 9	2008–2013	11,776	1/5/3	11	83	Moderate	Consistent	Imprecise	High
School and community	D, 1	2009	2,950	0/1/0	100	100	Moderate	NA	Precise	Insufficient
	PA, 1	2008	1,721	0/0/1	0	0	High	NA	Imprecise	Insufficient
	C, 4	1997–2012	5,416	0/2/2	25	75	High	Consistent	Imprecise	Moderate
School and consumer health informatics (CHI)	PA, 2	2007–2012	1,335	0/2/0	0	0	Moderate	Inconsistent	Imprecise	Insufficient
	C, 3	2006–2013	2,280	0/3/0	33	33	Moderate	Inconsistent	Imprecise	Insufficient
School, home and CHI	C, 1	2011	589	0/0/1	0	0	High	NA	Imprecise	Insufficient
Home based										
Home only	D, 1	2004	59	0/1/0	0	0	Moderate	NA	Imprecise	Insufficient
	C, 3	2001–2012	262	0/2/1	0	33	Moderate	Inconsistent	Imprecise	Low
Home, school and community	C, 1	2009	1,323	0/0/1	0	0	High	NA	Imprecise	Insufficient
Home, primary care and CHI	C, 1	2006	878	1/0/0	0	Unable to determine	Low	NA	Imprecise	Insufficient
Primary care setting										
Primary care	C, 1	2009	600	0/1/0	0	0	Moderate	NA	Imprecise	Insufficient
Primary care and home	C, 2	2012	253	1/1/0	50	50	Moderate	Inconsistent	Imprecise	Insufficient
Child care setting										
Child care	P, 2	2007–2012	827	0/0/2	50	50	High	Inconsistent	Imprecise	Insufficient
	C, 3	2009–2012	2,393	1/2/0	33	33	Moderate	Inconsistent	Imprecise	Low
Community based										
Community only	PA, 1	2010	46	0/1/0	0	0	Moderate	NA	Imprecise	Insufficient
Community and school	C, 3	1997–2010	2,966 plus 24 schools (mean enrolment 1109)	0/3/0	66	66	Moderate	Inconsistent	Imprecise	Moderate
Community, school and home	C, 1	2007–2008	1,326	0/1/0	100	100	Moderate	NA	Precise	Insufficient
Community and home	C, 2	2010	564	0/1/1	0	0	High	Consistent	Imprecise	Insufficient
Community, home, primary care and child care	C, 1	2010	43,811	0/1/0	100	100	Moderate	NA	Precise	Insufficient
Community, school, primary care and child care	D, 1	2010	NR	0/0/1	100	100	High	NA	Precise	Insufficient
Community, home, school and child care	C, 1	2013	2,631	0/0/1	0	50	High	NA	Imprecise	Insufficient

Risk of bias: The Downs and Black Checklist for Measuring Quality was used to assess the risk of bias in the included studies.
Consistency: The body of evidence was considered to be consistent in direction if ≥70% of the studies had an effect in the same direction.
Precision: We considered the body of evidence precise if ≥70% of the studies reported statistically significant results ($P < 0.05$) or had narrow confidence intervals that excluded the null.
Strength of the evidence: We considered the four recommended domains: (i) risk of bias in the included studies; (ii) direction of the evidence; (iii) consistency across studies and (iv) precision of the pooled estimate or the individual study estimates. We identified all studies as providing direct evidence since all of the studied interventions directly affected one of the study's primary outcomes of interest.
*Adiposity-related outcomes: for example, body mass index (BMI), BMI *z*-score, waist circumference and skin-fold thickness.
†Our original KQ6 focused on consumer health informatics-based interventions. These results are reported here under other KQs based on primary setting.
C, diet–PA combined interventions; D, diet-only intervention; NA, not applicable; NR, not reported; PA, PA-only intervention.

Table 2 Percentage (%) of childhood obesity prevention studies showing favourable adiposity-related outcomes by primary intervention setting and type of intervention*

Setting	Type of intervention, number of studies	% with statistically significant and favourable results ($P < 0.05$)				% with favourable results ($P < 0.05$ not necessary)			
		Diet-only interventions	PA-only interventions	Combined diet–PA interventions	Total	Diet-only interventions	PA-only interventions	Combined diet–PA interventions	Total
School based	D, 5; PA, 25; C, 85; Total, 115	80	28	36	36	100	64	64	66
Home based	D, 1; PA, 0; C, 5; Total, 6	0	–	0	0	0	–	20	17
Primary care based	D, 0; PA, 0; C, 3; Total, 3	–	–	33	33	–	–	33	33
Child care based	D, 0; PA, 2; C, 3; Total, 5	–	50	33	40	–	50	33	40
Community based	D, 1; PA, 1; C, 8; Total, 10	100	0	50	50	100	0	63	60
Total	D, 7; PA, 28; C, 104; Total, 139	71	29	35	36	86	61	60	62

*Our original KQ6/setting focused on consumer health informatics-based interventions. These results are reported here under other KQs based on primary setting.
C, diet–PA combined interventions; D, diet-only intervention; PA, PA-only intervention.

Table 3 Percentage (%) of childhood obesity prevention studies showing favourable adiposity-related outcomes by intervention setting(s) and type of intervention

Setting(s)	Type of intervention, number of studies	% with statistically significant and favourable results ($P < 0.05$)				% with favourable results (do not need to be $P < 0.05$)			
		Diet-only interventions	PA-only interventions	Diet–PA combined interventions	Total	Diet-only interventions	PA-only interventions	Diet–PA combined interventions	Total
1. Single setting interventions									
School only	D, 3; PA, 18; C, 40; Total, 61	67	22	44	39	100	72	53	61
Home only	D, 1; PA, 0; C, 3; Total, 4	0	–	0	0	0	–	33	25
Primary care only	D, 0; PA, 0; C, 1; Total, 1	–	–	0	0	–	–	0	0
Child care only	D, 0; PA, 2; C, 3; Total, 5	–	50	33	40	–	50	33	40
Community only	D, 0; PA, 1; C, 0; Total, 1	–	0	–	0	–	0	–	0
All single setting interventions (overall)	D, 4; PA, 21; C, 47; Total, 72	50	24	39	35	75	67	49	56
2. Multiple setting interventions*									
School and home	D, 1; PA, 3; C, 28; Total, 32	100	100	36	44	100	100	79	81
School and community	D, 1; PA, 1; C, 7; Total, 9	100	0	43	44	100	0	71	67
Community and home	D, 0; PA, 0; C, 2; Total, 2	–	0	–	0	–	0	–	0
School, home and community	D, 0; PA, 1; C, 11; Total, 12	–	0	18	17	–	0	77	71
All multiple setting interventions (overall)	D, 2; PA, 5; C, 48; Total, 55	100	60	40	44	100	60	74	74
Total	D, 6; PA, 26; C, 95; Total, 127	67	31	39	39	83	65	62	63

*School and community, both 'School and Community' and 'Community and School' based interventions. School and home and community, 'School, Home and Community', 'Home, School and Community', and 'Community, School and Home' based interventions.
C, diet–PA combined interventions; D, diet-only intervention; PA, PA-only intervention.

Effectiveness of school-based interventions

School only-based interventions

Sixty-one studies (60,576 participants) took place in a school-only setting, including 40 RCTs and 21 non-RCTs. Most enrolled elementary or middle school-aged children. Three RCTs, described in four articles, evaluated diet-only interventions (22–25) and showed a decrease in BMIs or BMI *z*-scores. They were designed to prevent weight gain and focused on promoting a healthy diet and reducing the consumption of carbonated drinks.

Eighteen studies tested PA-only interventions (Appendix A1). PA-only interventions had an impact on BMI (26), WC in girls (27), skin-fold thickness (28) and %BF (29) in children. One study with a significant effect on %BF (29) enrolled pre-pubertal girls in daily physical education classes. Some of the PA interventions also affected clinical outcomes by lowering systolic blood pressure (30) or affected intermediate outcomes by increasing PA and reducing sedentary activities (31,32).

Forty studies assessed the effect of combined strategy interventions (Appendix A2). These included intensive classroom PA lessons led by trained teachers, moderate-to-vigorous PA sessions, distribution of nutritional education materials and provision of healthful foods. Children who participated in longer term intervention programmes generally showed significant improvements in physical performance (e.g. shuttle run minutes) (33–37), whereas shorter studies mostly had non-significant results.

Five of the combined interventions were RCTs, reported BMI *z*-score as an outcome and had sufficient data for meta-analysis (38–42). Together, they showed an overall difference in BMI *z*-score of –0.05 (95% CI: –0.10, –0.01, $P = 0.025$) in favour of the intervention groups (Fig. 2a).

Nine of the combined interventions reported on BMI and were RCTs with sufficient data for meta-analysis (41–49). They showed an overall mean difference in BMI of –0.30 kg m^{-2} (95% CI: –0.45, –0.15, $P < 0.001$) in favour of the intervention (Fig. 2b).

Overall, SOE was moderate that interventions targeting diet or PA only in a school-only setting prevent obesity in children. SOE was presently insufficient that school only-based interventions using a combined strategy prevent obesity.

School-based interventions with a home component

Thirty-two studies (36,272 participants) implemented interventions in schools and included a home component, including 21 RCTs (Appendix A3). Only one study evaluated a diet-only intervention (50), where the most intensive of its two intervention arms showed a reduction in the prevalence of overweight and obesity. Three studies tested PA-only interventions (51–53). All four reported statistically significant beneficial effects of the intervention on adiposity-related outcomes.

Ten (36%) of the 28 studies that tested combined strategy interventions reported statistically significant beneficial effects (Table 1). Among the 18 studies that measured BMI change, 16 showed reduced BMI due to the intervention with differences ranging from –0.10 to –1.60 kg m^{-2}. However, only in five studies were these changes statistically significant.

Only one of the 28 examined studies reported a significant, desirable intervention effect on the combined prevalence of overweight and obesity (adjusted odds ratio [OR] = 0.67; 95% CI: 0.47, 0.96, $P < 0.03$) (54). Another study found a statistically significant difference in the prevalence of both overweight (3.7%, $P < 0.05$) and obesity (2.3%, $P < 0.05$), again favouring the intervention (55).

Eight combined intervention studies reported sufficient data for meta-analysis of BMI (56–63). The weighted mean BMI difference was –0.25 kg m^{-2} (95% CI: –0.68, 0.17, $P = 0.237$) favouring the interventions (Fig. 2c).

SOE was insufficient that diet-only interventions prevent obesity when implemented in a school setting with a home component. SOE was high that PA-only interventions prevent obesity, but was moderate regarding diet–PA combined interventions.

School-based interventions with home and community components

We identified 10 studies (14,605 participants) that were school based and included both home and community components, including five RCTs (Appendix A4). Most of the combined interventions focused on providing education to improve diet and PA. SOE was insufficient that PA-only interventions prevent obesity as there was only one study found with a moderate ROB. SOE was high that combined interventions prevent obesity as the only study had a low ROB and the other studies, which mostly had moderate ROB, showed favourable intervention effects.

School-based interventions with a community component

Six studies (10,087 participants) were school-based with a community component, including three RCTs (Appendix A5). One RCT tested a diet-only intervention and showed significant improvements in BMI and obesity prevalence (64). Another RCT testing PA-only interventions found positive but insignificant improvements in triceps skin-fold thickness and body weight, but no improvements in BMI or %BF (65). Four studies evaluating combined interventions generally showed non-significant improvements in adiposity-related outcomes.

SOE was insufficient that diet- or PA-only interventions prevent obesity given only one study for each. SOE was

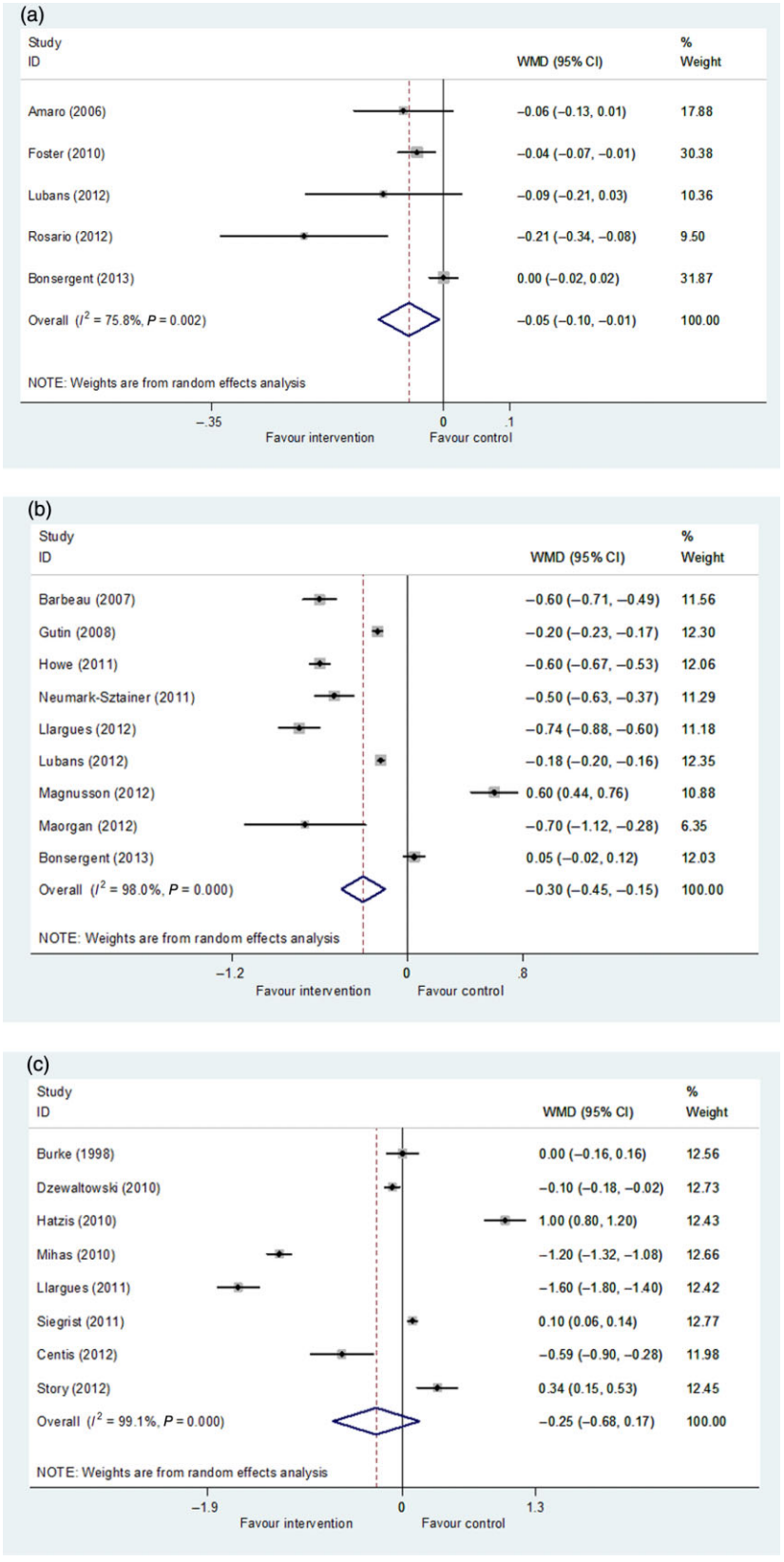

Figure 2 Meta-analyses of changes in body mass index (BMI) and BMI *z*-score of school-based, diet–physical activity combined childhood obesity prevention studies. (a) Change in BMI *z*-score in studies taking place only in school. (b) Change in BMI in studies taking place only in school. (c) Change in BMI in studies taking place in school with a home-based intervention component. WMD, weighted mean difference.

moderate that combined interventions prevent obesity as two of the four studies with moderate ROB both showed favourable effects.

School-based interventions with a consumer health informatics component

We identified five studies (3,615 participants) that were school based with a CHI component (Appendix A6). One reported a significant difference in BMI between the intervention and control groups (66). SOE was insufficient regarding such interventions.

School-based interventions with home and consumer health informatics components

One non-RCT evaluated a combined intervention (589 participants) in a school setting with both home and CHI components, but detected no beneficial effects on adiposity-related outcomes (67). Hence, SOE was insufficient.

Key findings from non-school-based interventions

Home only-based interventions

We identified four home-based intervention studies (321 participants) and all were RCTs (Appendix A7). One examined a diet-only intervention and three tested combined interventions. None of the studies detected a statistically significant beneficial intervention effect on adiposity-related outcomes. SOE was insufficient for diet-only interventions. SOE was low that combined interventions at home to prevent obesity.

Home-based interventions with school and community components

We identified one RCT intervention study (1,323 participants), which was home based and included both school and community components. It reported no effect of a diet–PA combined intervention on BMI (68). SOE was insufficient that such interventions prevent obesity in these settings.

Home-based studies with primary care and consumer health informatics components

One RCT (878 participants) was home based with both primary care and CHI components. It reported no effect of a combined diet and PA intervention on BMI *z*-score (69). SOE was insufficient for this intervention strategy.

Primary care only-based interventions

We identified one quasi-experimental study (600 participants) that was only primary care based (70). It did not reduce obesity rates. Thus, SOE was insufficient regarding interventions in this setting.

Primary care-based interventions with a home component

Two RCTs (71,72) (253 participants) assessed the effect of combined interventions performed in a primary care setting with a home component. Only one found significant differences in BMI *z*-score in favour of the intervention group (72). Thus, SOE was insufficient for such interventions.

Child care centre only-based interventions

We identified five child care centre-based intervention studies (3,220 participants) (73–77), three of which were RCTs (73–75) and two non-RCTs. The two non-RCTs both assessed the effects of PA-only interventions. One of them found significant differences in BMI and %BF between the intervention and control groups (76). The other one found positive but insignificant differences in BMI between intervention and control ($P = 0.09$ for weight and intervention interaction). However, with only two studies, SOE was insufficient regarding the PA-only interventions.

The three RCT studies (73–75) all evaluated diet–PA combined interventions, but only one (75) showed significant beneficial effects on adiposity-related outcomes. SOE was low for combined interventions as these RCTs had moderate ROB and inconsistent results.

Community-based or environmental-level interventions

We identified 10 community-based or environmental-level intervention studies (Appendix A8). The strongest evidence came from three studies that took place in the community with school involvement (78–80). Two were RCTs with one conducted in the Netherlands (1,108 participants) (78) and the other in the United States (mean enrolment of 1,109 participants across 24 schools) (79). The third was a non-RCT in the United States (80). The US RCT (79) and the one non-RCT (80) detected statistically significant, beneficial intervention effects.

SOE was moderate that community-based, diet–PA combined interventions that include a school component prevent obesity. SOE was insufficient for interventions implemented in the community alone or with support from other settings.

Consumer health informatics interventions

Seven CHI studies were identified and they took place primarily in the school or home setting. Only one (66) school-based CHI study showed a significant reduction in BMI in the intervention group.

Discussion

To our knowledge, this is the most comprehensive study that has been performed to evaluate the success of various childhood obesity prevention programmes. We included

139 studies conducted in multiple settings in high-income countries over the past three decades, focusing on adiposity-related outcomes and SOE. The study followed the rigorous protocol required by the AHRQ for systematic reviews and provides important findings to help various stakeholders understand the effectiveness of obesity prevention programmes for children and to offer insights for future research and intervention development. This study has a number of principal strengths and makes some unique contributions to the field (see below). Our key findings include:

First, we find that a large number of childhood obesity prevention studies have been performed, but the majority are school based and conducted in the United States and within the most recent decade. In total, we identified 139 intervention studies, 115 (83%) of which were school based.

Second, we find at least moderate SOE to support the effectiveness of school-based interventions. About half of the studies reported statistically significant beneficial intervention effects for at least some of the adiposity-related measures. Interventions implemented in schools with home involvement had the highest proportion of studies with favourable results.

Third, overall, a greater proportion of multi-setting studies demonstrated significant and beneficial results compared with single-setting interventions. All settings combined, the highest proportion of significant and favourable impacts on adiposity-related outcomes was attributable to diet-only interventions while the lowest proportion of successes lies in PA-only interventions.

Fourth, the SOE varied by intervention strategy and setting. SOE for PA-only interventions delivered in schools with home involvement and diet–PA combined interventions delivered in schools with both home and community components to prevent obesity were high. SOE for school only-based interventions targeting either diet or PA, combined diet–PA school-based interventions with home or community components, and combined diet–PA community-based interventions with a school component to prevent obesity was moderate. SOE for combined interventions in a child care or home setting to prevent obesity was low. In general, some intervention groupings had low SOE due to the small number of relevant studies conducted of their type. The SOE for the effectiveness of interventions in other settings was insufficient due to the small number of published research found, the moderate or high ROB and conflicting results across studies.

In general, our main findings are consistent with previous systematic reviews that school-based interventions can help prevent obesity in children. This supports the IOM's recommendations (12) that schools be the focal point for childhood obesity prevention. However, discrepancies between our findings and previous reviews exist, especially regarding the SOE and the magnitude of intervention effects. Although our study generally found an insufficient-to-moderate SOE supporting the intervention effects of school-based interventions (although there were a few exceptions of large intervention effects in some cases), the most recent Cochrane review found strong evidence to support the beneficial effects of school-based intervention programmes, particularly among children aged 6–12 (16). However, another systematic review of 18 controlled trials did not find any significant improvements in BMI with school-based PA interventions (81). The discrepancies may stem from differences in study selection criteria and, therefore, included studies, as well as from differences in the outcomes being examined.

Although some of the intervention studies we reviewed reported large effect sizes in changes in BMI and obesity/overweight prevalence, overall, our meta-analyses, which was based on all available studies meeting our inclusion criteria, suggest the effect size of these interventions to be small. For example, our findings presented in Fig. 2 imply improvements of about 0.05 *z*-score and 0.25 BMI. Especially compared with the increase in BMI and the rates of overweight and obesity over the last three decades in many countries, these intervention effects are slight. Thus, the effectiveness of interventions to reverse the tide of the epidemic is likely to be small as many large social and environmental changes are driving the trend towards increasing obesity. In general, our reported effect sizes were similar to those reported by other reviews of preventive interventions, although there are also reviews that did not find any significant improvements in BMI with school-based interventions (81).

Our findings have some important implications for clinical decision and policy making. This review can help clinical and public health practitioners, researchers and policy makers decide on appropriate intervention strategies with which to combat the prevailing obesity epidemic in developed countries. It may also help provide insights for future research. We need more research to test non-school-based interventions and those utilizing innovative designs and approaches. Strong, promising results suggest that school-based childhood obesity prevention programmes may fight the rise in childhood obesity. After careful review of the individual components of the successful studies, healthcare professionals may replicate the results in new settings, which could lead to broader implementation.

The cost-effectiveness of the interventions was infrequently studied. Only a few of our included studies mentioned such analyses and none of the studies we reviewed reported estimates of the resources used (costs) to achieve the observed effects. It is likely that few studies collected data on the costs associated with their interventions. Given the complexity of many programmes, it is understandably challenging to determine which costs should be accounted

for (e.g. programme development, implementation, maintenance costs) and, subsequently, assessed and reported. Nevertheless, it would be important to know how stakeholders (e.g. parents, schools, public health professionals, government agencies) would calculate the real value of an intervention. It would also be important to figure out how researchers may help in such assessments. This is a critical gap in the current literature. In the future, we recommend researchers, journal editors and funding agencies to encourage the collection and reporting of data on the cost-effectiveness of interventions.

The sustainability of interventions and their beneficial effects are another important, albeit complex and controversial, issue that is less studied. Very few studies measured or showed that intervention effects were sustained beyond the active intervention period. More future research, including systematic reviews, is needed in this area.

Intervention programmes may also have potential harms, although few were reported. For example, programmes may unintentionally cause stigmas; most interventions achieved only small or no effects but weighed and measured many youth. Some of the youth may have anticipated improvement in their weight status, but could have experienced no significant improvements or benefits. Thus, it is foreseeable that some youth could feel a sense of failure with this or an associated loss in self-esteem. Although, we did not observe any reports of this in the literature. Nonetheless, future research into the potential harms of interventions would be useful.

In addition, it is possible that some intervention approaches may elicit the desire to respond favourably in some children, particularly those from families with higher educational attainment and/or greater financial resources. This may lead to disproportionate behavioural and weight improvements in these groups. Future research is needed to assess this possibility and better understand the issue to help enhance intervention effectiveness.

This study has several limitations. First, it was limited in scope by focusing only on studies from high-income countries. However, this restriction makes the findings all the more applicable to the examined population. Second, there was great heterogeneity in the included studies in terms of intervention setting, design, sample size and characteristics, intervention approach, primary measures used to assess intervention effects, length of follow-up, and statistical and analytical approaches taken. Such variability made it challenging for cross-comparisons. Third, given that we identified so few studies outside of the school setting, we were only able to conduct meta-analyses for KQ1 (school-based interventions) and only on a small number of studies at that.

Fourth, we stratified analyses first based on study setting and then by intervention strategy taken (diet, PA or both combined). However, due to limited sample sizes, we could not further stratify analyses – for example, to explore the comparative effectiveness of specific intervention approaches (e.g. educational interventions vs. environmental interventions) with pooled analyses or compare effects in specific intermediate outcomes (e.g. changes in fruit and vegetable intake vs. total energy intake).

Fifth, we used BMI and BMI-related measures, such as BMI *z*-score and BMI percentile, as well as the prevalence of overweight and obesity based on BMI cut-points, as the primary outcomes of interest. This was performed given its more common reporting across included studies. But, BMI has its limitations. It is an indirect measure of adiposity and not an ideal indicator for health risk. In addition, studies used different BMI cut-points to define overweight and obesity.

Sixth, related to study heterogeneity, another challenge was that studies assessed intervention effects in different ways. Some did so by comparing changes in the outcomes between the intervention and control groups while other studies compared between-group differences in weight outcomes only at follow-up. Still others reported on ORs of being overweight and/or obese and other studies did so on between-group difference in continuous outcome measures such as BMI. This again made comparing and pooling results challenging.

Seventh, we included some studies that did not state obesity prevention among their original intervention goals but rather stated they aimed to reduce cardiovascular risk. We kept these studies in the review because they also implemented diet and/or PA interventions and reported on body weight-related outcomes for their results. By employing similar strategies on similar outcomes, they could also shed some light on the potential effects of childhood obesity interventions. However, because of the differences in original study intents, these studies may differ slightly with those originally designed to primarily target childhood obesity.

Lastly, considering the comparability of studies conducted in different locales, we limited our review to only those studies conducted in high-income countries. Thus, our findings may not be generalizable to lower income countries. In addition, we decided to reduce the inclusion requirement for length of follow-up time to 6 months for school-based studies considering the usual length of school years. However, we recognize 6 months may be too short a time to observe intervention effects on weight-related outcomes.

Despite these many limitations, our study was systematic and rigorous. We followed standardized procedures from the AHRQ Effective Healthcare Program and utilized input from various experts and stakeholders in the field of childhood obesity prevention. Only experimental studies, quasi-experimental studies and natural experiments were included in our analyses to minimize confounding and

Table 4 Recommendations for future research in childhood obesity prevention based on our systematic review

Although we have found promising effects for school-based interventions for childhood obesity prevention, many questions still remain unanswered. We recommend additional research in the following areas:

1. Intervention studies conducted in non-school-based settings: The literature on interventions that take place in settings other than schools is sparse. We need more studies that test environmental and policy-based interventions. Also, very few preventive studies took place in clinical settings such as in primary care practices. Primary healthcare providers could play an important role in childhood obesity prevention by providing healthful eating and exercise guidelines to children and their parents, as well as by regularly monitoring body weight.
2. Innovative study design and intervention approaches: Drawing upon established behavioural theories and strategies when designing interventions may help researchers increase their success in childhood obesity prevention. For example, only a few studies used social marketing to inform the delivery of messages on nutrition, PA and health. Studies may integrate this approach with other intervention components to promote healthful lifestyle changes. Consumer health informatics may have promise. However, only seven studies used consumer health informatics in our study and only one significantly reduced obesity risk.
3. Systems science-guided intervention studies: Obesity is the result of a complex mix of biological, behavioural, social, economic and environmental factors. An effective and sustainable strategy for obesity prevention may have to target many factors. Applying a systems science approach in intervention design, implementation and evaluation can take into account multiple risk factors as well as the complex interactions and feedback loops between them.
4. Potential differential effects of interventions across subgroups: Research into population subgroups (e.g. given gender, age, race/ethnicity or socioeconomic status) and the potentially different responses across groups to the same intervention may help tailor and target future interventions to maximize beneficial impacts. Most of the studies included in this review did not report their results by population subgroup.
5. Programmes of greater statistical power: Interventions with larger sample sizes and lengthier follow-up are important. Most of the interventions we reviewed resulted in modest behavioural changes. Many factors can potentially affect individual dietary and PA behaviours so the study sample or follow-up time may not be sufficiently large or long enough for an intervention's impact to be seen.
6. Publication of intervention process evaluation results: Publication of process evaluation results from the intervention's implementation should be encouraged. Such knowledge is important to carry out translational research and for the scaling up of public health interventions. Very few of the studies we reviewed here reported process evaluation results. Future studies may consider building in process evaluation during the intervention design, data collection and final analysis stages.
7. Application of rigorous analytical approaches: More rigorous analytical approaches are needed to better analyse repeated measures often collected during longer term follow-up periods, to control for potential confounding variables remaining after randomization and to test for effect modification and heterogeneity in the treatment or intervention effect.
8. Assessment of the intervention cost-effectiveness: Although challenging, cost-effectiveness analyses will add important value to an intervention's evaluation. Such information is also important for the promotion and dissemination of effective interventions as well as for informing policymakers' decisions. Very few studies reported obesity prevention programme costs.
9. Obesity prevention research in adolescents: Obesity in adolescents has been found to be more predictive of obesity during adulthood than obesity in younger children. Adolescence is an important stage of life when young people are exposed to various social and environmental factors that establish lifelong life habits. Although studies examined in this review included children aged 2–18, analyses could not be limited to teens as results were not reported in this manner. As recommended earlier, subgroup-oriented research may offer in-depth information on obesity prevention important to consider for this life stage.
10. Potential harms: The implementation of intervention programmes may also have potential harms, such as inciting stigma when implemented on a large scale to many children but to little or no effects (as was observed with most studies included in our review). Children enrolled in obesity prevention programmes are weighed and/or measured and may anticipate improvements. If no significant improvements (or benefits) were observed, some may feel a sense of failure or lowered self-esteem. Although we did not see evidence of this in the studies we reviewed, future research is needed to examine this issue more in-depth.

PA, physical activity.

maximize utilization of available evidence. Our study assessed the effects of the interventions on multiple adiposity-related outcomes while most other reviews have focused only on BMI or other select outcomes. We have also identified a number of future research priorities for the field (see Table 4 for our recommendations).

In conclusion, a large number of childhood obesity intervention studies have been conducted in high-income countries, but they have been predominantly conducted in schools and in the United States. The following intervention points are supported by a body of evidence of at least a moderate level of strength to be effective for childhood obesity prevention: (i) schools are an important setting in which to implement effective intervention programmes and concomitant involvement of the home/family and community is desirable; (ii) improving access to PA facilities and healthful food choices such as fruits and vegetables both at school and home is effective and (iii) home or parental and family involvement is important. Overall, there is moderate-to-high SOE to support the idea that diet and/or PA interventions implemented in schools prevent obesity. However, the evidence on the effectiveness of interventions implemented in other settings is generally insufficient. Other analyses and findings from this systematic review on other outcomes such as on blood pressure and blood lipids can be found and were reported recently elsewhere (82,83).

Future research is needed to evaluate interventions conducted in settings other than in schools, especially those

implementing wide-ranging changes through regional and national policy and environmental changes. Research into the delivery and effectiveness of innovative intervention strategies, such as those taking advantage of and applying new technologies and approaches (e.g. health communication and social marketing, urban planning), established behavioural theories and novel methodologies (e.g. systems science) is also of great importance.

Authors' contributions

Youfa Wang is the study's principal investigator. RFW is the project manager. Yang Wu is the project coordinator. Study concept and design were contributed by Youfa Wang, JS, LJC, RFW and Yang Wu. All authors and some other research team members were responsible for acquisition of data. All authors participated in the analysis and interpretation of data. Youfa Wang, RFW, Yang Wu, JS and LC drafted the manuscript. All authors were responsible for the critical revision of the manuscript for important intellectual content. LC, OF, BDL, RFW and Youfa Wang performed statistical analysis. Youfa Wang, RFW and JS conducted administrative, technical or material support. Study supervision was provided by Youfa Wang and RFW.

Conflict of interest statement

No conflict of interest was declared.

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Appendix A References for studies cited in the Result section (A1–A8)

This systematic review included 147 articles, which described 139 intervention studies. Appendix A provided additional references that were not included in the paper due to the journal's page limit.

Appendix A1 PA-only interventions implemented in a school only-based setting

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