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Review article

Effectiveness of school-based health promotion interventions prioritized by stakeholders from health and education sectors: A systematic review and meta-analysis

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ABSTRACT

Childhood obesity and associated modifiable risk factors exert significant burden on the health care system. The goal of this systematic review and meta-analysis was to examine the effectiveness of school-based intervention types perceived by Canadian stakeholders in health and education as feasible, acceptable and sustainable in terms of improving physical activity (PA), fruit and vegetable intake, and body weight. We searched multiple databases for studies that evaluated school-based interventions to prevent obesity and associated risk factors (i.e., unhealthy diet, physical inactivity, sedentary behaviour) in children aged 4–18 years from January 1, 2012 to January 28, 2020. From 10,871 identified records, we included 83 and 80 studies in our systematic review and meta-analysis, respectively. Comprehensive School Health (CSH) and interventions which focused on modifications to school nutrition policies showed statistically significant positive effects on fruit intake of 0.13 (95% CI: 0.04, 0.23) and 0.30 (95% CI: 0.1, 0.51) servings per day, respectively. No intervention types showed statistically significant effect on vegetable intake. CSH, modifications to physical education (PE) curriculum, and multicomponent interventions showed statistically significant difference in BMI of −0.26 (95% CI: −0.40, −0.12), −0.16 (95% CI: −0.3, −0.02), and −0.18 (95% CI: −0.29, −0.07), respectively. CSH interventions showed positive effect on step-count per day, but no other types of interventions showed significant effect on any of PA outcome measures. Thus, the results of this systematic review and meta-analysis suggest that decision-makers should carefully consider CSH, multicomponent interventions, modifications to PE curricula and school nutrition policies to prevent childhood obesity.

1. Introduction

Physical inactivity and unhealthy diet are established risk factors that increase the odds of childhood overweight and obesity 3.5- (McGavock et al., 2009) and 2-fold (Dubois et al., 2007). As a result of more than 80% of adolescents worldwide being inactive (World Health Organization, 2018) and only a negligible minority of them consuming the recommended intake of vegetables and fruits (World Health Organization, 2003), over 340 million children and adolescents aged 5–19 had overweight or obesity in 2016 (World Health Organization, 2018). In developed countries, the prevalence of overweight and obesity has increased substantially over the past three decades: from 16.9% in boys and 16.2% in girls in 1980 to 23.8% and 22.6%, respectively, in 2013 (Ng et al., 2014). Due to its prevalence and deleterious consequences in later life, childhood obesity and associated modifiable risk factors exert significant burden on the health care system (Tremmel et al., 2017).

To improve diet and physical activity (PA) and curb rising obesity rates among children, various jurisdictions have focused efforts and resources on school-based health promotion interventions which have been lauded as an effective approach since they reach a wide range of children over a prolonged period of time (Fung et al., 2012). Previous systematic reviews focused on evaluating school-based interventions in terms of their effectiveness (Wang et al., 2015; Harris et al., 2009;

Abbreviations: BMI, body mass index; CI, confidence interval; CSH, Comprehensive School Health; FV, fruit and vegetable; HSAT, Healthy School Action Tools; MVPA, moderate to vigorous physical activity; PA, physical activity; PE, physical education; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; SES, socioeconomic status; RCT, randomized controlled trial; UK, United Kingdom

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Hynynen et al., 2016; Brown and Summerbell, 2009; Katz et al., 2008; Safron et al., 2011; da Silveira et al., 2013). A systematic review of 139 obesity prevention interventions showed significant effects on both body mass index (BMI) z scores and BMI, with interventions that involve multiple components appearing more promising (Wang et al., 2015). For example, Harris et al. (2009) found that interventions targeting only physical activity (PA) failed to improve BMI in children. Katz et al. (2008) previously reached the same conclusion and showed a significant positive effect on body weight reduction of interventions combining PA and healthy diet.

Despite the valuable contribution of these knowledge syntheses to our understanding of efficacy and effectiveness of such interventions, they lack information about feasibility, acceptability, sustainability, cost-effectiveness, and return on investment of these interventions. To circumvent this gap and to equip decision-makers with relevant and actionable information, we took a novel approach to conducting a systematic review. We facilitated focus group discussions with stakeholders in health and education sectors to determine which school-based health promotion intervention *types* were perceived as the most *feasible, acceptable, and sustainable in the Canadian context* (Montemurro et al., 2018). The goal of the present systematic review and meta-analysis was to examine the effectiveness of interventions that belonged to the prioritized types, for specific outcomes (i.e., PA, fruit and vegetable [FV] intake, and adiposity) that were selected to guide the future step: assessing cost-effectiveness and return on investment of these interventions to fully inform decision makers.

2. Methods

2.1. Identification of priority areas through facilitated focus groups

We used participatory qualitative research methods to convene a group of 45 Canadian stakeholders with expertise and prolonged engagement in school health. They included practitioners working directly with school communities (e.g., educators, administrators), government employees within health and education ministries, and researchers in education, public health, nutrition, and kinesiology, sport and recreation. Participants were led through facilitated discussions to review and define all responses, and build group consensus on the most important key considerations to inform prioritization of the intervention types, such as research/evidence based, sustainability, acceptability, feasibility, and whole-school/comprehensive. Stakeholders identified and prioritized through a cumulative voting exercise the following 7 school-based intervention types (in rank order) (Montemurro et al., 2018):

- Interventions based on the *comprehensive school health (CSH) approach* with a focus on increasing PA, decreasing sedentary behaviour, and promoting healthy eating through changes to the whole school community;
- Interventions based on *modifications of school nutrition policies* (e.g., implementation of competitive food policies);
- *Universal school food program* interventions that promote involvement of children in food production (e.g., school gardens), preparation (e.g., school kitchens), and waste management;
- Interventions that increase *provision of healthy foods in schools* with the active involvement of food suppliers and food service staff to ensure the availability and appeal of healthy food choices;
- Interventions involving *modifications of the existing physical education (PE) classes* delivered by PE specialists, in terms of their duration and/or quality;
- *Promotion of PA outside of PE classes* (e.g., changing the school environment to increase active and/or unstructured play);
- Interventions *changing foods/drinks sold and/or served in schools* through installment of water fountains, banning unhealthy foods and beverages, and changing options offered by vending machines.

2.2. Search strategy

In partnership with a librarian, we executed a search in PROSPERO, OVID Medline, OVID EMBASE, OVID PsycINFO, OVID ERIC, Cochrane Database of Systematic Reviews < 2005 > , EBSCO CINAHL, Proquest Dissertations and Theses Global databases, using controlled vocabulary (e.g., MeSH, Emtree) and key words representing the concepts "obesity" and "school based interventions". Studies situated in daycares and other out-of-school programs were excluded. Searches were limited to January 1, 2012 to January 28, 2020, since a comprehensive review on school-based obesity prevention programmes from inception to April 2013 was previously conducted by Wang et al. (2015) Articles considered by Wang et al. (2015) were included at the abstract review stage if they reported on dietary, PA, or adiposity outcome measures, and were school-based intervention studies. No other limits were applied. The search strategy syntax adapted for all databases is available in Supplementary Table 1A. Database of researcher-identified literature and trial Registries (https://.clinicaltrials.gov and http://www.who.int/ictrp/en/) were also searched for relevant grey literature.

2.3. Eligibility criteria

The search focused on comparative studies that evaluated school-based interventions to prevent obesity and associated risk factors (i.e., unhealthy diet, physical inactivity, sedentary behaviour) in school-aged children (4–18 years old). Non-comparative studies and those interventions that targeted children who were overweight or obese at baseline were excluded. To ensure that identified studies were appropriate to the Canadian context, we included only those conducted in countries with human development index of 0.80 or greater (United Nations Development Programme, 2017). Additionally, the identified interventions had to include outcome assessment at least 6 months following the baseline assessment and had to include information on the following outcomes: FV intake (servings or times per day), PA (minutes of moderate to vigorous physical activity [MVPA] and step counts), and/or adiposity (BMI, BMI z-score, BMI percentile, % overweight and/or obese).

2.4. Data abstraction and management

Articles were uploaded into systematic review data management software Covidence (Veritas Health Innovation Ltd.). Following duplicate removal, two research assistants independently reviewed titles and abstracts; any discrepancies were resolved by a third reviewer. Research assistants followed an exclusion criteria decision tree to define the exclusion reason for studies (Supplementary Table 1B). During full text review, reviewers independently tagged articles relevant to the 7 prioritized types to be considered for data extraction. Interventions with 1 or more of the 7 prioritized types of interventions and/or additional intervention components were considered *multicomponent*.

Four research assistants were involved (at different points in time) in extracting the following data: program/policy type; authors; title; country; study design; study duration; intervention setting and description of delivery; sample size and characteristics; and detailed results on the aforementioned outcome measures. The accuracy of the extracted data was then checked by two other research assistants.

2.5. Quality assessment

We assessed the methodological quality of included studies using the Downs and Black checklist (Downs and Black, 1998). Similar to Wang et al. (2015) we included 7 questions in our assessment: 1) Is the hypothesis/aim/objective of the study clearly described? 2) Are the main outcomes to be measured clearly described in the introduction or methods? 3) Are the characteristics of the study subjects clearly described? 4) Are the interventions of interest clearly described? 5) Are the main findings of the study clearly described? 6) Were study subjects randomized to intervention groups? 7) Was the randomized intervention assignment concealed from both subjects and those conducting the study until recruitment was complete and irrevocable?

Papers were considered of low methodological quality if they did not do or describe more than 3 of the above items and were excluded from further analysis. Additional questions were used to assess the validity and reliability of each outcome measure. Measures of FV intake were considered valid and reliable if studies cited sources demonstrating the accuracy of the outcome measure; and PA and adiposity outcomes—if they described the use of objective instruments.

2.6. Data synthesis

For each included study, we collected the following information: first author, year of publication, area/country, program name, settings, study designs, duration of the intervention and follow-up time points, sample size, age group targeted by the intervention, and criteria used for subgroup analysis (if conducted). We examined randomized controlled trial (RCT) studies to obtain information about the unit of randomization and the number of intervention and control groups. In addition, we extracted data on effectiveness of interventions in terms of the outcomes of our interest. The effect measures included mean differences for continuous outcomes and odds ratios for categorical outcomes and the 95% confidence intervals.

We carried out meta-analysis using valid and reliable effect measures for each of the prioritized intervention types and did not attempt to combine effects across intervention types. Within each intervention type, we aggregated any 2 or more effects on the same outcome and same effect measure. All meta-analyses were done using a random effects model. For FV consumption, we combined studies that reported effects in terms of servings. To transform intake in grams and times per day, we used assumptions that each serving is 80 g (World Health Organization, 2004) and servings per day and times per day are used interchangeably. The Cochrane Q and I^2 statistic were used to test the degree of heterogeneity. Publication bias was assessed by visual inspection of funnel plots and regression-based Egger test for small-study effects. The results were statistically significant when two-sided p values were less than 5%. All analyses were conducted in STATA v. 14 (Stata Corporation, College Station, Texas, USA). The review follows Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) reporting guidelines (Supplementary Table 1C).

3. Results

3.1. Search results

A total of 10,301 records were identified through database searching and 570 additional records were identified through other sources (e.g., articles included and excluded by Wang et al. (2015) researcher identified studies), see PRISMA flow chart in Supplementary Fig. S1. The 83 studies included in final data extraction (Table 1) were published between 2001 and 2020; 80 studies were included in meta-analysis. Studies represented 66 different school-based interventions implemented in 18 countries. Most studies were conducted in the United States (n = 17), followed by ten in Australia, eight in Canada, seven each in Denmark and Spain, six each in the United Kingdom (UK) and Norway, and New Zealand, four in Germany, two each in Ireland, Italy, Switzerland and France, and one in Belgium, Sweden, South Korea, and Israel.

3.2. Description of the included studies

Study numbers by prioritized intervention type were as follows: CSH approach (n = 18), modifications of school nutrition policies (n = 1), universal school food program (n = 2), provision of healthy foods in schools (n = 4), modifications of the existing PE curriculum (n = 18), promotion of PA outside of PE classes (n = 8), changing foods/drinks sold and/or served in schools (n = 3), and multi-component interventions (n = 29). Risk of bias summary is shown in Table 2. The sample size varied from 82 (Harman, 2014) to 1,065,562 (Schwartz et al., 2016) students. RCT design was employed in 56 studies, with school being the unit of randomization in 50 studies (Table 3). The duration of the interventions ranged from three months (Damsgaard et al., 2014) to seven years (Rush et al., 2014; Tarp et al., 2018). Most of the interventions (n = 35) lasted approximately 1 academic year and out of these intervention, 28 assessed only short-term impacts (e.g., at the end of the intervention as the latest time point), while only 3 studies included a follow-up period of 1 year (Nogueira et al., 2017; Farmer et al., 2017; Dewar et al., 2013), and one each included a follow-up of 3 (Meyer et al., 2014); 4 (Hobin et al., 2017), and 7 (Bere et al., 2014) years post-intervention. Forty-four papers reported subgroup analysis based on age group, sex, race/ethnicity, parental education, socioeconomic status, weight status, rurality, activity group, intervention school, school vs. non-school days and hours, and semesters.

FV intake outcomes of interest were reported in 18 studies; PA outcomes of interest in 28 studies (step-counts, n = 19, and MVPA, n = 19). The following adiposity outcomes were measured in 70 studies: BMI (n = 41), BMI z score (n = 35), BMI percentile (n = 7), and % obesity and/or overweight (n = 27).

Based on the statistical testing reported in the included studies, positive effect of the interventions on vegetable or fruit intake was noted in seven studies (five (Waters et al., 2018; Bjelland et al., 2015; Alaimo et al., 2013; Perry et al., 2004; Llargues et al., 2011) and two (Sahota et al., 2001; Damsgaard et al., 2014) on fruit and vegetable intake, respectively, Table 4). Positive effect of the interventions on one of the PA outcome measures was noted in eight studies (Bell et al., 2017; Benden et al., 2014; Donnelly et al., 2009; Grydeland et al., 2013; Kriemler et al., 2010; Spencer et al., 2014; Sutherland et al., 2016; Vander Ploeg et al., 2014); two studies that reported no change for the total sample observed positive long-term effect (Farmer et al., 2017) and effect in girls (Grydeland et al., 2013). Positive effect of the interventions on at least one of the adiposity outcomes of interest was reported in 27 studies (Ekwaru et al., 2017; Millar et al., 2011; Lazaar et al., 2007; Sacchetti et al., 2013; Azevedo et al., 2014; Jansen et al., 2011; Kriemler et al., 2010; Hollis et al., 2016; Story et al., 2012; Marcus et al., 2009; Aperman-Itzhak et al., 2018; Bartelink et al., 2019; Lubans et al., 2012; Yang et al., 2017; Ariza et al., 2019; Scherr et al., 2017; Fetter et al., 2018; Erfle and Gamble, 2015; Reed et al., 2013; Klakk et al., 2013; Learmonth et al., 2019; Schwartz et al., 2016; Muckelbauer et al., 2009; Llargues et al., 2011; Recasens et al., 2019; Llargués et al., 2012; Llargués et al., 2017); ten studies reported no changes for the total sample, but showed positive effect among girls (Grydeland et al., 2014), boys (Breheny et al., 2020; Yang et al., 2017), low socioeconomic status (SES) groups (De Coen et al., 2012), long-term (Bere et al., 2014; Bugge et al., 2012; Hollis et al., 2016; Adab et al., 2018; Ickovics et al., 2019), incidence and prevalence of overweight (as opposed to obesity) (Foster et al., 2008).

3.3. CSH approach (n = 18)

From seven studies (Sahota et al., 2001; Waters et al., 2018; Merrotsy et al., 2019; Bjelland et al., 2015; Malakellis et al., 2017; Millar et al., 2011; De Coen et al., 2012) which reported on FV consumption, positive changes were reported in two studies on fruit (Waters et al., 2018; Bjelland et al., 2015) and one study on vegetable (Sahota et al., 2001) intake. Five studies (Vander Ploeg et al., 2014; Ofosu et al., 2018; Grydeland et al., 2013; O'Leary et al., 2019; Toftager et al., 2014) reported on PA outcomes: one study (Vander Ploeg et al., 2014) reported positive effect on step-counts; the other study (Grydeland et al., 2013) reported improvement in step-counts in boys,

Table 1
Characteristics of included studies, grouped by stakeholders' prioritized type.

First author, year, citation	Area/Country	Program name	Study design	Intervention duration	Assessment time points	Sample size	Age group[a] (Grade level, age range, mean (SD) age)	Subgroup analysis of the effectiveness reported by
Comprehensive school health approach (n = 18)								
Reed et al., 2008)	BC/Canada	Action schools! BC	Cluster RCT	1 academic year	at the end of the intervention	268	9–11 years old	–
Vander Ploeg et al., 2014	AB/Canada	APPLE Schools	Quasi-experimental, pre-post trial with a parallel, nonequivalent control group	2.5 years (from Jan 2008 to June 2011)	compared students in 2009 and 2011, cross-sectional samples of Grade 5	1157	Grade 5	school and non-school days and hours
Ekwaru et al., 2017	AB/Canada	APPLE Schools	Incremental cost-effectiveness analysis	2.5 years (from Jan 2008 to June 2011)	compared students in 2009 and 2011, cross-sectional samples of Grade 5	Not reported	Grade 5	–
Ofosu et al., 2018	Canada	APPLE Schools	Quasi-experimental, repeated measures longitudinal study	2.5 years	7-year follow-up	540	13.8 (1.4) at follow-up for APPLE Schools students; 14.0 (1.3) at follow-up for Comparison Schools students	weight status (overweight, obesity), PA (typical week, school days, non-school days, school hours, non-school hours)
Sahota et al., 2001	United Kingdom	APPLES	Cluster RCT	1 academic year	at the end of the intervention	636	7–11 years old	weight status (overweight, obese)
Waters et al., 2018	Australia	Fun 'n healthy in Moreland!	Cluster RCT	3.5 years	1 year into the intervention and at the end of it	3167	5–12 years old	–
Grydeland et al., 2014	Norway	HEIA	Cluster RCT	20 months	at the end of the intervention	1324	Grade 6; 11.2 (0.3) years old	sex; parental education (low, medium, high)
Grydeland et al., 2013	Norway	HEIA	Cluster RCT	20 months	at the end of the intervention	700	Grade 6; 11.2 (0.3) years old	sex; activity group (low, high), weight status (normal, overweight), parental education (12 years and less, 12–16 years, and more than 16 years), school vs. after school hours
Bjelland et al., 2015	Norway	HEIA	Cluster RCT	20 months	at the end of the intervention	1396	Grade 6; 11.2 (0.3) years old	parental education (low, medium, high), sex, weight status (normal vs overweight)
Malakellis et al., 2017	Australia	It's Your Move	Quasi-experimental, repeated measures longitudinal study	3 years	2-year follow up[b]	880	12–16 years old	intervention schools (A, B, C)
Millar et al., 2011	Australia	It's Your Move – Pacific Obesity Prevention in Communities Project	Quasi-experimental using a longitudinal cohort follow-up	3 years	at the end of the intervention	3040	12–18 years old; 14.6 (1.42) years old	–
De Coen et al., 2012	Belgium	Prevention of Overweight among Pre-school and school children (POP) project	Cluster RCT	2 academic years	at the end of the intervention	1589	3–6 years old; 4.95 (1.31) years old	SES[c] (low, medium, high)
Rush et al., 2012	New Zealand	Project Energize	Cluster RCT	2 years	at the end of the intervention	1352	5–7 and 10–12 years old	sex, age (younger vs. older), ethnicity (European, Maori, other), weight status (obese, overweight, obese or overweight, normal), rural vs urban schools
Rush et al., 2014	New Zealand	Project Energize	Cluster RCT	7 years	7-year follow up	4804	6–11 years old	sex, age (younger vs. older), SES (low, medium, high), ethnicity (European, Maori, other)
Martínez-Vizcaíno et al., 2020	Spain	MOVI-KIDS	Cluster RCT	8 months	at the end of the intervention	1434	4–7 years old	sex
O'Leary et al., 2019	Ireland	Project Spraoi	Cluster RCT	1.5 years	at the end of the intervention	231	6, 10 years old	age (6 and 10 years old)
Merrotsy et al., 2019	Ireland	Project Spraoi	Cluster RCT	1.5 years	at the end of the intervention	101	6, 10 years old	–
Toftager et al., 2014	Denmark	SPACE study	Cluster RCT	2 years	at the end of the intervention	797	11–13 years old	–
Modifications of school nutrition policies (n = 1)								

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Table 1 (*continued*)

First author, year, citation	Area/Country	Program name	Study design	Intervention duration	Assessment time points	Sample size	Age group[a] (Grade level, age range, mean (SD) age)	Subgroup analysis of the effectiveness reported by
Alaimo et al., 2013	USA	School Nutrition Advances Kids project	Cluster RCT	22 months	at the end of the intervention	1777	Grade 7; 12.3 (0.6) years old	sex
Universal school food program (n = 2)								
Polonsky et al., 2019	USA	School Breakfast Program	Cluster RCT	2.5 years	at 1.5- and 2.5-year follow-up	1362	Grade 4–6, 10.8 (0.96) years old	–
Vik et al., 2019	Norway	School Meal Project	Quasi-experimental	1 year	6- and 12-month follow-up	164	10–12 years old	–
Provision of healthy foods in schools (n = 4)								
Perry et al., 2004	USA	Cafeteria Power Plus	Cluster RCT	2 academic years	at the end of the intervention	1668	Grade 1 and 3	–
Bere et al., 2014	Norway	Fruits and Vegetables Make the Marks	Cluster RCT	1 academic year	at the end of the intervention, and 1, 3, and 7 years post-intervention	320	10–12 years old	sex, parental education (low, high), grade (6 vs 7)
Scherr et al., 2017	USA	Shaping Healthy Choices Program	Cluster RCT	9 months	at the end of the intervention	436	Grade 4; 9–10 years old	district (Northern California, Central Valley, combined)
Fetter et al., 2018	USA	Shaping Healthy Choices Program	Cluster RCT	9 months	at the end of the intervention	304	Grade 4, 9–10 years old	–
Modification of existing PE curriculum (n = 18)								
Erfle and Gamble, 2015	USA	Active Schools Program	Quasi-experimental	1 academic year	at the end of the intervention	10,206	Grade 6–8	sex, weight status (i.e., at-risk (overweight or obese) vs. not at-risk)
Walther et al., 2009	Germany	–	Cluster RCT	1 year	at the end of the intervention	188	Grade 6; 11.1 (0.7) years old	–
Müller et al., 2016	Germany	–	Cluster RCT	4 years	yearly till the end of the intervention	366	Grade 5 and 6; 11.5 (0.61) years old	sex
Reed et al., 2013	USA	–	Quasi-experimental	1 academic year	at the end of the intervention	470	Grade 2 to 8	sex, age group (elementary vs. middle school)
Klakk et al., 2013	Denmark	CHAMPS-Study DK	Quasi-experimental	2 years	at the end of the intervention	632	Grade 2 to 4; 7.7–12 years old	weight status (overweight snd obese vs normal)
Learmonth et al., 2019	Denmark	CHAMPS-Study DK	Natural experiment	2 years	at the end of the intervention	1009	Grade 1–6, 5–12 years old; 8.4 (1.4) years old	weight status (normal weight, overweight/obesity), sex
Tarp et al., 2018	Denmark	CHAMPS-Study DK	Quasi-experimental design	6.5 years	6.5-year follow up	312	5–12 years old; 7.8 (1.3) years old	–
Bugge et al., 2012	Denmark	The Copenhagen School Child Intervention Study	Quasi-experimental	3 years	4 years post-intervention	696	6–7 years old	sex
Resaland et al., 2011	Norway	The Sogndal School-Intervention Study	Quasi-experimental	2 years	at the end of the intervention	256	Grade 4; 9.2 (0.3) years old	–
Lazaar et al., 2007	France	–	Cluster RCT	6 months	at the end of the intervention	425	6–10 years old	sex, weight status (normal, obese)
Thivel et al., 2011	France	–	Cluster RCT	6 months	at the end of the intervention	457	6–10 years old	weight status (normal, obese)
Weeks and Beck, 2012	Australia	–	RCT	1 academic year	at the end of the intervention	99	Grade 9; 13.8 (0.4) years old	sex
Sacchetti et al., 2013	Italy	–	Cluster RCT	2 years	at the end of the intervention	497	Grade 3; 8–9 years old	sex
Hart, 2014	USA	HEAL Alabama	Quasi-experimental; secondary analysis	20 weeks	at the end of the intervention	508	10–11 years old	–
Hobin et al., 2017	Canada	Physical Education/ Health Education credits	Natural experiment	1 academic year	4 years post-intervention	33,619	Grade 11 and 12; 15.8 (0.71) years old	grade, sex, weight status, school neighborhood
Ten Hoor et al., 2018	Netherlands	–	Cluster RCT	1 year	at the end of the intervention	695	11–15 years old; 12.97 (0.54) years old	–
Lucertini et al., 2013	Italy	–	Cluster RCT	6 months	at the end of the intervention	101	Grade 3–5	–
Nogueira et al., 2017	Australia	CAPO Kids	Cluster RCT	9 months	9- and 21-month follow up	240	12.3 (0.6) years old	–
Promotion of PA outside of the PE classes (n = 8)								
Donnelly et al., 2009	USA	Physical Activity Across the Curriculum (PAAC)	Cluster RCT	3 years	at the end of the intervention	1527	Grade 2–3	days of the week (weekend vs weekday), hours of the day (during school, after school, evening)

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Table 1 (*continued*)

First author, year, citation	Area/Country	Program name	Study design	Intervention duration	Assessment time points	Sample size	Age group[a] (Grade level, age range, mean (SD) age)	Subgroup analysis of the effectiveness reported by
Ford et al., 2013	United Kingdom	–	Quasi-experimental	15 weeks	15 weeks post-intervention	152	5–11 years old	–
Harman, 2014	USA	T.R.A.I.L.S.	Quasi-experimental	1 academic year	baseline-midpoint (Thanksgiving) – at the end of the intervention	82	High school students; 15.7 years old	–
Azevedo et al., 2014)	United Kingdom	–	Natural experiment	1 year	at the end of the intervention	497	11–13 years old	–
Farmer et al., 2017	New Zealand	PLAY	Cluster RCT	1 academic year	baseline – 1 year – 2 years (i.e., 1 year post-intervention)	840	8 years old	time of the day (whole day, school day, break time, lunch time)
Benden et al., 2014	USA	–	Cluster RCT	1 academic year	in the Fall and Spring semesters	337	8.5 years old on average	semesters (Fall, Spring), sex, grade (2 vs 4), ethnicity (Black, Hispanic, Asian), weight status (overweight, obese)
Breheny et al., 2020	UK	Daily Mile	Cluster RCT	12 months	4-[d] and 12-month follow-up	2280	8.9 (1.0) years old	sex, year group (Year 3 and 5), high and low deprivation, ethnicity (white, non-white)
Have et al., 2018	Denmark	–	Cluster RCT	10 months	at the end of the intervention	505	7.2 (0.3) years old	–
Changing foods/drinks sold and/or served in schools (n = 3)								
Damsgaard et al., 2014	Denmark	–	Cluster RCT	3 months	at the end of the intervention and 3 months post-intervention	834	8–11 years old	–
Schwartz et al., 2016	USA	–	Quasi-experimental	4 years	used databases of cafeteria equipment deliveries between the 2008–2009 and 2012–2013	1,065,562	Elementary and middle schools	sex
Muckelbauer et al., 2009)	Germany	–	Cluster RCT	1 academic year	at the end of the intervention	2950	8.3 (0.7) years old	–
Multicomponent interventions (n = 29)								
Llargues et al., 2011	Spain	The Avall Study	Cluster RCT	2 years	at the end of the intervention	509	5–6 years old; 6.03 (0.3) years old	–
Recasens et al., 2019	Spain	AVall	Cluster RCT	2 years	8 years post-intervention	509	5–6 years old	–
Llargués et al., 2012	Spain	AVall	Cluster RCT	2 years	at the end of the intervention and 2 years post-intervention	426	5–6 years old; 6.03 (0.3) years old	–
Llargués et al., 2017	Spain	AVall	Cluster RCT	2 years	6-year follow-up	566	5–6 years old	–
Foster et al., 2008	USA	School Nutrition Policy Initiative	Cluster RCT	2 years	at the end of the intervention	1349	Grade 4 to 6	weight status (overweight, obese), age, race/ethnicity, sex
Rappaport et al., 2013	USA	School Nutrition Policy Initiative	Cluster RCT	2 years	at the end of the intervention and 2 years post-intervention	8186	Kindergarten to Grade 8	Sex, age group (K-4 vs. Grade 5–8), race (White, African American, Hispanic, Asian, Other)
Parsons et al., 2014	USA	Anchorage School District's Wellness Policy	Secondary data analysis of two cohorts	4 years	5-year follow up	7222	Elementary schools	sex, race/ethnicity (Caucasian vs. Minority), SES (not enrolled in Title I school vs. enrolled in Title I school)
Jansen et al., 2011	Netherlands	Lekker Fit!	Cluster RCT	1 academic year	at the end of the intervention	2622	Grade 3 to 8; 6–12 years old	age group (younger (Grade 3–5) vs. older (Grade 6–8))
Kriemler et al., 2010	Switzerland	KISS	Cluster RCT	1 academic year	at the end of the intervention	502	Grade 1 (6.9 (0.3) years old) and Grade 5 (11 (0.5) years old)	in vs out of school
Meyer et al., 2014	Switzerland	KISS	Cluster RCT	1 academic year	at the end of the intervention and 3 years post-intervention	289	Grade 1; 6.9 (0.3) years old	–
Hollis et al., 2016	Australia	Physical Activity 4 Everyone (PA4E1)	Cluster RCT	2 years	1 year from the baseline and at the end of the intervention	1150	Grade 7; 11–13 years old	sex, baseline BMI (underweight/healthy weight, overweight/;obese), baseline physical activity level (active. Inactive)

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Table 1 (*continued*)

First author, year, citation	Area/Country	Program name	Study design	Intervention duration	Assessment time points	Sample size	Age group[a] (Grade level, age range, mean (SD) age)	Subgroup analysis of the effectiveness reported by
Sutherland et al., 2016	Australia	Physical Activity for Everyone (PA4E1)	Cluster RCT	2 years	12 months from the baseline and at the end of the intervention	1150	Grade 7; 12 years old	–
Story et al., 2012	USA	Bright Start	Cluster RCT	45 weeks	at the end of the intervention	454	Kindergarten and Grade 1; 5.84 (0.53) years old	–
Marcus et al., 2009	Sweden	STOPP	Cluster RCT	4 years	at the end of the intervention	3135	Grade 1 to 4; 6–10 years old	sex, weight status, calendar year
Santos et al., 2014)	Canada	Healthy Buddies	Cluster RCT	1 academic year	at the end of the intervention	647	6–12 years old	age group (younger, older), weight status (overweight or obese, normal)
Spencer et al., 2014	Canada	Heart Healthy Kids (H2K)	Quasi-experimental	6 months	at the end of the intervention	808	Grade 4–6; 9.9 (1.0) years old	sex
Bell et al., 2017	Canada	The AHEAD (Activity and Healthy Eating in Adolescence) Study	Cluster RCT	1 academic year	at the end of the intervention	928	12–13 years old	–
Adab et al., 2018	UK	WAVES study	Cluster RCT	12 months	at 15-, 30-, and 39-month follow-up	1392	5–6 years old; 6.3 (0.3) years old	weight status (obese, obese or overweight)
Griffiths and Griffiths, 2019	UK	–	Quasi-experimental	1 year	at the end of the intervention	646	7–12 years old; 9.4 (1.2) in the intervention group, 9.5 (1.2) in the control group	–
Aperman-Itzhak et al., 2018	Israel	–	Quasi-experimental	1 year	at the end of the intervention	396	Grade 5 and 6; 10–12 years old	weight status (normal weight, overweight and obese)
Bartelink et al., 2019)	Netherlands	Healthy Primary Schools of Future (HPSF)	Quasi-experimental	2 years	at 1- and 2-year follow-up	1676	4–12 years old; 7.5 (2.16) years old	–
Ickovics et al., 2019	USA	–	Cluster RCT	3 years	at 1-, 2-, and 3-year follow-up	595	10.9 (0.62) years old	–
Kennedy et al., 2018	Australia	Resistance Training for Teens'	Cluster RCT	10 weeks	at 6- and 12-month follow-up	607	14.1 (0.5) years old	–
Pablos et al., 2018	Spain	Healthy Habits Program	Cluster RCT	8 months	at the end of the intervention	158	10–12 years old, 10.66 (0.71) years old	–
Dewar et al., 2013	Australia	Nutrition and Enjoable Activity for Teen (NEAT) Girls	Cluster RCT	1 year	2-year follow-up	357	Grade 8; 13.2 (0.5) years old	–
Lubans et al., 2012	Australia	Nutrition and Enjoable Activity for Teen (NEAT) Girls	Cluster RCT	12 months	at the end of the intervention	357	12–14 years old; 13.18 (0.45) years old	–
Yang et al., 2017	Korea	–	Quasi-experimental	1 year	at the end of the intervention	768	9–10 years old; 12–13 years old	weight status (normal, overweight, obese), sex, age (10 or less year (elementary school), greater than10 year (middle school))
Weber et al., 2017	Germany	Be smart. Join in. Be fit.	Quasi-experimental	10 months	at the end of the intervention	195	Grade 3–4	sex, 6 days vs weekend
Ariza et al., 2019	Spain	POIBA	Quasi-experimental	1 year	at the end of the intervention	3073	9–10 years old	–

[a]Considering the heterogeneity of reporting in the selected papers, we present all available information.
[b]Please note that the duration of the study was 3 years.
[c]Socioeconomic status (SES).
[d]Not included in the analysis.

Table 2
Risk of bias summary.

First author, year, citation	Is the hypothesis/aim/objective of the study clearly described?	Are the main outcomes to be measured clearly described in the introduction or methods?	Are the characteristics of the study subjects clearly described?	Are the interventions of interest clearly described?	Are the main findings of the study clearly described?	Were study subjects randomized to intervention groups?	Was the randomized intervention assignment concealed from both subjects and those conducting the study until recruitment was complete and irrevocable?
Comprehensive school health approach (n = 18)							
Reed et al., 2008)	yes	no	no	yes	yes	yes	no
Vander Ploeg et al., 2014	yes	yes	yes	yes	yes	no	N/A
Ekwaru et al., 2017	yes	yes	no	yes	yes	no	N/A
Ofosu et al., 2018	yes	yes	yes	yes	yes	no	N/A
Sahota et al., 2001	yes	yes	yes	no	no	yes	no
Waters et al., 2018	yes	yes	yes	yes	no	yes	yes
Grydeland et al., 2014	yes	yes	yes	no	no	yes	no
Grydeland et al., 2013	yes	yes	yes	no	yes	yes	no
Bjelland et al., 2015	yes	yes	yes	no	no	yes	no
Malakellis et al., 2017	yes	yes	yes	yes	yes	no	N/A
Millar et al., 2011	yes	yes	yes	no	yes	no	N/A
De Coen et al., 2012	yes	yes	yes	yes	yes	yes	no
Rush et al., 2012	yes	yes	yes	yes	no	yes	yes
Rush et al., 2014	yes	yes	yes	yes	no	yes	yes
Martínez-Vizcaíno et al., 2020	yes	yes	yes	yes	yes	yes	no
O'Leary et al., 2019	yes	yes	yes	yes	yes	yes	no
Merrotsy et al., 2019	yes	yes	yes	yes	yes	yes	no
Toftager et al., 2014	yes	yes	yes	yes	yes	yes	no
Modifications of school nutrition policies (n = 1)							
Alaimo et al., 2013	yes	yes	yes	yes	no	yes	no
Universal school food program (n = 2)							
Polonsky et al., 2019	yes	yes	yes	yes	no	yes	no
Vik et al., 2019	yes	yes	yes	yes	yes	no	N/A
Provision of healthy foods in schools (n = 4)							
Perry et al., 2004	yes	yes	yes	no	no	yes	no
Bere et al., 2014	yes	yes	yes	yes	no	yes	no
Scherr et al., 2017	yes	yes	yes	yes	yes	yes	yes
Fetter et al., 2018	yes	yes	yes	yes	yes	yes	no
Modification of existing PE curriculum (n = 18)							
Erfle and Gamble, 2015	yes	yes	yes	yes	yes	no	N/A
Walther et al., 2009	yes	yes	yes	yes	no	yes	no
Müller et al., 2016	yes	yes	yes	yes	yes	yes	no
Reed et al., 2013	yes	yes	no	yes	yes	no	N/A
Klakk et al., 2013	yes	yes	yes	no	yes	no	N/A
Learmonth et al., 2019	yes	yes	no	yes	yes	no	N/A
Tarp et al., 2018	yes	yes	yes	yes	yes	no	N/A
Bugge et al., 2012	yes	yes	yes	yes	yes	no	N/A
Resaland et al., 2011	yes	yes	yes	yes	yes	no	N/A
Lazaar et al., 2007	yes	yes	yes	yes	yes	yes	no
Thivel et al., 2011	yes	yes	yes	yes	yes	yes	no

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Table 2 (*continued*)

First author, year, citation	Is the hypothesis/aim/objective of the study clearly described?	Are the main outcomes to be measured clearly described in the introduction or methods?	Are the characteristics of the study subjects clearly described?	Are the interventions of interest clearly described?	Are the main findings of the study clearly described?	Were study subjects randomized to intervention groups?	Was the randomized intervention assignment concealed from both subjects and those conducting the study until recruitment was complete and irrevocable?
Weeks and Beck, 2012	yes	yes	yes	no	yes	yes	no
Sacchetti et al., 2013	yes	yes	no	no	yes	yes	no
Hart, 2014	yes	yes	yes	yes	yes	no	N/A
Hobin et al., 2017	yes	yes	yes	no	yes	no	N/A
Ten Hoor et al., 2018	yes	yes	yes	yes	yes	yes	no
Lucertini et al., 2013	yes	yes	yes	yes	yes	yes	no
Nogueira et al., 2017	yes	yes	yes	no	yes	yes	no
Promotion of PA outside of PE classes (n = 8)							
Donnelly et al., 2009	yes	yes	no	no	yes	yes	no
Ford et al., 2013	yes	yes	no	yes	no	yes	no
Harman, 2014	yes	yes	no	yes	yes	no	N/A
Azevedo et al., 2014)	yes	yes	yes	yes	yes	no	N/A
Farmer et al., 2017	yes	yes	no	yes	yes	yes	no
Benden et al., 2014	yes	yes	no	yes	no	yes	no
Breheny et al., 2020	yes	yes	yes	yes	yes	yes	no
Have et al., 2018	yes	yes	yes	yes	yes	yes	no
Changing foods/drinks sold and/or served in schools (n = 3)							
Damsgaard et al., 2014	yes	yes	yes	yes	yes	yes	no
Schwartz et al., 2016	yes	yes	yes	yes	no	no	N/A
Muckelbauer et al., 2009)	yes	yes	yes	no	yes	yes	no
Multicomponent interventions (n = 29)							
Llargues et al., 2011	yes	yes	yes	yes	no	yes	no
Recasens et al., 2019	yes	yes	yes	yes	yes	yes	no
Llargués et al., 2012	yes	no	no	yes	yes	yes	no
Llargués et al., 2017	yes	no	no	yes	yes	yes	no
Foster et al., 2008	yes	yes	yes	no	yes	yes	no
Rappaport et al., 2013	yes	yes	yes	no	no	yes	yes
Parsons et al., 2014	yes	yes	no	yes	yes	no	N/A
Jansen et al., 2011	yes	yes	yes	yes	yes	yes	no
Kriemler et al., 2010	yes	yes	yes	no	yes	yes	yes
Meyer et al., 2014	yes	yes	yes	yes	yes	yes	yes
Hollis et al., 2016	yes	yes	yes	no	yes	yes	yes
Sutherland et al., 2016	yes	yes	yes	yes	yes	yes	no
Story et al., 2012	yes	yes	yes	yes	no	yes	no
Marcus et al., 2009	yes	yes	yes	yes	no	yes	no
Santos et al., 2014)	yes	yes	yes	yes	no	yes	no
Spencer et al., 2014	yes	yes	yes	yes	yes	no	N/A
Bell et al., 2017	yes	yes	no	yes	yes	yes	no
Adab et al., 2018	yes	yes	yes	yes	yes	yes	no

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Table 2 (*continued*)

First author, year, citation	Is the hypothesis/aim/objective of the study clearly described?	Are the main outcomes to be measured clearly described in the introduction or methods?	Are the characteristics of the study subjects clearly described?	Are the interventions of interest clearly described?	Are the main findings of the study clearly described?	Were study subjects randomized to intervention groups?	Was the randomized intervention assignment concealed from both subjects and those conducting the study until recruitment was complete and irrevocable?
Griffiths and Griffiths, 2019	yes	yes	yes	yes	yes	no	N/A
Aperman-Itzhak et al., 2018	yes	yes	yes	yes	yes	no	N/A
Bartelink et al., 2019)	yes	yes	yes	yes	yes	no	N/A
Ickovics et al., 2019	yes	yes	yes	yes	yes	yes	no
Kennedy et al., 2018	yes	yes	yes	yes	no	yes	no
Pablos et al., 2018	yes	yes	no	yes	no	yes	no
Dewar et al., 2013	yes	yes	yes	no	no	yes	no
Lubans et al., 2012	yes	yes	no	yes	yes	yes	no
Yang et al., 2017	yes	yes	yes	yes	yes	no	N/A
Weber et al., 2017	yes	yes	yes	yes	yes	no	N/A
Ariza et al., 2019	yes	yes	yes	yes	yes	no	N/A

Table 3
Characteristics of the included RCTs.

	Unit of randomization	Number of schools/students in the intervention (I) and control arms (C), I:C
Comprehensive school health approach (n = 13)		
Reed et al., 2008	School	6:2
Sahota et al., 2001	School	5:5
Waters et al., 2018	School	12:10
Grydeland et al., 2014	School	12:25
Grydeland et al., 2013	School	12:25
Bjelland et al., 2015	School	12:25
De Coen et al., 2012	School	18:13
Rush et al., 2012	School	62:62
Rush et al., 2014	School	193:unknown
Martínez-Vizcaíno et al., 2020	School	11:10
O'Leary et al., 2019	School	2:2
Merrotsy et al., 2019	School	1:1
Toftager et al., 2014	School	7:7
Modifications of school nutrition policies (n = 1)		
Alaimo et al., 2013	School	16 (HSAT): 4 (SNAK): 18 (MSBE): 17 (Control)
Universal school food program (n = 1)		
Polonsky et al., 2019	School	8:8
Provision of healthy foods in schools (n = 4)		
Perry et al., 2004	School	13:13
Bere et al., 2014	School	9:29
Scherr et al., 2017	School	2:2
Fetter et al., 2018	School	1:1
Modification of existing PE curriculum (n = 9)		
Walther et al., 2009	Class	4:3
Müller et al., 2016	Class	7:7 (and additional 2 "High level" groups)
Lazaar et al., 2007	School	14:5
Thivel et al., 2011	School	14:5
Weeks and Beck, 2012	Student	43:38
Sacchetti et al., 2013	Class	unknown
Ten Hoor et al., 2018	School	4:5
Lucertini et al., 2013	School	1:1:1
Nogueira et al., 2017	School	1:1
Promotion of PA outside of PE classes (n = 5)		
Donnelly et al., 2009	School	14:10
Farmer et al., 2017	School	8:8
Benden et al., 2014	Class	12:12
Breheny et al., 2020	School	20:20
Have et al., 2018	School	6:6
Changing foods/drinks sold and/or served in schools (n = 2)		
Damsgaard et al., 2014	Year group within schools	9 schools (crossover design), unclear about the number of control and intervention schools
Muckelbauer et al., 2009)	School	17:15
Multicomponent interventions (n = 21)		
Llargues et al., 2011	School	8:8
Recasens et al., 2019	School	8:8
Llargués et al., 2012	School	8:8
Llargués et al., 2017	School	8:8
Foster et al., 2008	School	5:5
Rappaport et al., 2013	School	5:5
Jansen et al., 2011	School	10:10
Kriemler et al., 2010	Class	16 classes (9 schools):12 classes (6 schools)
Meyer et al., 2014	School	16 classes (9 schools):12 classes (6 schools)
Hollis et al., 2016	School	5:5
Sutherland et al., 2016	School	5:5
Story et al., 2012	School	7:7
Marcus et al., 2009	School	5:5
Santos et al., 2014	School	10:10
Bell et al., 2017	School	3:3
Adab et al., 2018	School	26:28

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Table 3 (*continued*)

	Unit of randomization	Number of schools/students in the intervention (I) and control arms (C), I:C
Ickovics et al., 2019	School	3:3:3:3
Kennedy et al., 2018	School	8:8
Pablos et al., 2018	School	2:2
Dewar et al., 2013	School	6:6
Lubans et al., 2012	School	6:6

no changes in MVPA in the total sample but positive changes in girls. Among the 14 studies (Reed et al., 2008; Ekwaru et al., 2017; Ofosu et al., 2018; Sahota et al., 2001; Waters et al., 2018; Grydeland et al., 2014; Malakellis et al., 2017; Millar et al., 2011; De Coen et al., 2012; Rush et al., 2012, 2014; Martínez-Vizcaíno et al., 2020; O'Leary et al., 2019; Merrotsy et al., 2019) that used one or more adiposity outcome measures, three (Ekwaru et al., 2017; Millar et al., 2011; Rush et al., 2014) found a significant positive effect on at least one of the measures; nine (Reed et al., 2008; Malakellis et al., 2017; Rush et al., 2012; Ofosu et al., 2018; Sahota et al., 2001; Waters et al., 2018; Martínez-Vizcaíno et al., 2020; O'Leary et al., 2019; Merrotsy et al., 2019) reported non-significant effects; and two (Grydeland et al., 2014; De Coen et al., 2012) reported mixed results with no changes in the total sample and positive changes in female students (Grydeland et al., 2014) and those of low SES (De Coen et al., 2012). No studies used BMI percentile as an outcome measure.

When combined, these interventions showed statistically significant difference in BMI of −0.26 (95% confidence interval [CI]: −0.4, −0.12), fruit intake of 0.13 servings/times per day (95% CI: 0.04, 0.23), and step-count per day (1155.76, 95% CI 449.77, 1861.75) (Table 5, Fig. S2). However, no statistically significant difference was found in BMI z score (−0.02, 95% CI: −0.04, 0.01), odds of being overweight (0.89, 95% CI: 0.58, 1.38) and obese (0.84, 95% CI: 0.64, 1.12) or overweight/obese (0.85, 95% CI: 0.71, 1.01), vegetable intake (0.12, 95% CI: −0.01, 0.25), step-count per minute (20.7, 95% CI: −46.23, 87.63) and MVPA (−0.67, 95% CI: −4.39, 3.05).

3.4. Modifications of school nutrition policies (n = 1)

A study by Alaimo et al. (2013) aimed to test the effectiveness of several interventions based on the Healthy School Action Tools (i.e., HSAT) on FV intake, but no data was available for PA and obesity outcomes of interest. This study reported significant positive effect on fruit intake in two intervention arms (i.e., HSAT only, and Michigan State Board of Education Nutrition policy), but not in the third one (i.e., School Nutrition Advances Kids Team). Increase in vegetable consumption was not significant. Meta-analysis of the three arms showed significant increase in the number of servings of fruits per day (0.30, 95% CI: 0.01, 0.51), but not vegetables (−0.02, 95% CI: −0.10, 0.06).

3.5. Universal school food program (n = 2)

Only interventions in two studies (Polonsky et al., 2019; Vik et al., 2019) were categorized as universal school food programs. None of the studies included FV intake or PA outcomes of interest. While both studies reported non-significant changes in BMI z scores and prevalence of overweight/obese in the total samples, Polonsky et al. (2019) and Vik et al. (2019) reported negative results for prevalence of obese in the intervention group BMI z score 12 months following the beginning of the intervention respectively.

Meta-analysis showed no significant difference between intervention and control groups in terms of BMI z score (0.05, 95% CI: −0.05, 0.15), odds of obesity (1.25, 95% CI: 0.94, 1.66) and overweight/obesity (1.21, 95% CI: 0.95, 1.55).

3.6. Provision of healthy foods in schools (n = 4)

Three (Perry et al., 2004; Bere et al., 2014; Scherr et al., 2017) out of four (Perry et al., 2004; Bere et al., 2014; Scherr et al., 2017; Fetter et al., 2018) studies reported on FV consumption, but only one (Perry et al., 2004) showed a statistically significant positive effect on fruit intake. Three studies reported on adiposity outcome measures: one (Bere et al., 2014) showed no effect on BMI and prevalence of overweight/obese (with positive effect noted in long-term follow-up), while another study (Scherr et al., 2017) found significant positive effects on BMI z scores, and two (Scherr et al., 2017; Fetter et al., 2018) studies showed positive effect on BMI percentile. Only one (Fetter et al., 2018) study measured and reported non-significant changes in MVPA.

One (Bere et al., 2014) study measured effect of the intervention on BMI score at two time points; aggregate effect measures of BMI (−0.33, 95% CI: −0.94, 0.28) were not significant, while effect measures were significantly different in terms of BMI percentile (−7.92, 95% CI: −16.53, 0.7). No data on PA or FV intake were pooled in the meta-analysis.

3.7. Modifications of existing PE curriculum (n = 18)

No studies reported on FV outcomes. None of the four studies (Tarp et al., 2018; Bugge et al., 2012; Hobin et al., 2017; Ten Hoor et al., 2018) reporting on PA outcomes showed a significant effect. Fifteen studies (Lucertini et al., 2013; Nogueira et al., 2017; Erfle and Gamble, 2015; Walther et al., 2009; Müller et al., 2016; Reed et al., 2013; Klakk et al., 2013; Learmonth et al., 2019; Bugge et al., 2012; Resaland et al., 2011; Lazaar et al., 2007; Thivel et al., 2011; Weeks and Beck, 2012; Sacchetti et al., 2013; Hart, 2014) reported on adiposity outcomes of interest. Two studies (Erfle and Gamble, 2015; Sacchetti et al., 2013) showed positive effect on BMI and another study (Bugge et al., 2012) reported positive long-term changes (as opposed to no short-term effect). One study (Weeks and Beck, 2012) reported no changes in BMI for the total sample, but negative changes for girls. Positive changes on BMI percentile were noted in one study (Reed et al., 2013) in female elementary school students (no effect for male elementary school students and male and female middle school students). One study (Lazaar et al., 2007) showed positive effects on BMI z scores, and two studies (Klakk et al., 2013; Learmonth et al., 2019) showed positive effects on % overweight/obese, with no significant changes when stratified by sex (Learmonth et al., 2019).

Meta-analysis showed statistically significant difference in BMI of −0.16 (95% CI: −0.3, −0.02) and odds of overweight/obesity 0.41 (95% CI: 0.23, 0.73), as opposed to no difference in BMI z score (0.0, 95% CI: −0.06, 0.06), BMI percentile (−0.68, 95% CI: −1.42, 0.06), odds of being obese (0.85, 95% CI: 0.51, 1.41), step-count per minute (10.5, 95% CI: −63.81, 84.81) and MVPA minutes per day (−1.47, 95% CI: −3.4, 0.46).

3.8. Promotion of PA outside of PE classes (n = 8)

Six studies (Donnelly et al., 2009; Ford et al., 2013; Have et al., 2018; Azevedo et al., 2014; Farmer et al., 2017; Benden et al., 2014) reported on PA outcomes: one study (Donnelly et al., 2009) demonstrated positive effect on both PA outcomes and one study (Farmer et al., 2017) demonstrated mixed results with positive effects noted one year after the end of the intervention but not immediately following the intervention. One study (Azevedo et al., 2014) reported negative effects on total PA. From seven (Breheny et al., 2020; Have et al., 2018; Donnelly et al., 2009; Ford et al., 2013; Harman, 2014; Azevedo et al., 2014; Farmer et al., 2017) studies reporting on adiposity outcomes, two studies reported statistically significant positive effect on BMI in the total sample (Azevedo et al., 2014) and boys (Breheny et al., 2020).

The studies included in meta-analysis showed no overall mean difference in any of the outcomes of interest: BMI (−0.18, 95% CI: −0.39,

Table 4
Effectiveness of the interventions in terms of adiposity, PA, and fruit and vegetable consumption outcomes as reported by the authors of the included studies.

First author, year, citation	Outcome measures Adiposity outcome measures BMI	BMI z scores	BMI percentile	% overweight and/or obese	PA outcome measures MVPA	Step-counts	Fruit and vegetable consumption fruit	vegetables
Comprehensive School Health (n = 18)								
Reed et al., 2008	ns							
Vander Ploeg et al., 2014						+		
Ekwaru et al., 2017				+				
Ofosu et al., 2018				ns		ns		
Sahota et al., 2001		ns					ns	+/ns[a]
Waters et al., 2018	ns	ns		ns			+	ns
Grydeland et al., 2014	ns/+[b]	ns/+[c]						
Grydeland et al., 2013					ns/+[d]	+/ns[e]		
Bjelland et al., 2015							+	ns
Malakellis et al., 2017	ns	ns		ns			ns	ns
Millar et al., 2011	ns	+		ns			ns	ns
De Coen et al., 2012		ns/+[f]					ns	ns
Rush et al., 2012		ns						
Rush et al., 2014	+	+		+/ns[g]				
Martínez-Vizcaíno et al., 2020	ns	ns		ns				
O'Leary et al., 2019		ns		ns	ns			
Merrotsy et al., 2019	ns						ns	
Toftager et al., 2014					ns	ns		
Modifications of school nutrition policies (n = 1)								
Alaimo et al., 2013							+/ns[h]	ns
Universal School Food Program (n = 2)								
Polonsky et al., 2019		ns		ns/-[i]				
Vik et al., 2019		ns/-[j]						
Provision of healthy foods in schools (n = 4)								
Perry et al., 2004							+	ns
Bere et al., 2014	ns			ns/+[k]			ns	
Scherr et al., 2017		+	+				ns	ns
Fetter et al., 2018			+		ns[l]			
Modifications of existing PE curriculum (n = 18)								
Erfle and Gamble, 2015	+		ns					
Walther et al., 2009		ns						
Müller et al., 2016			ns					
Reed et al., 2013			+/ns[m]					
Klakk et al., 2013	ns			+				
Learmonth et al., 2019				+/ns[n]				
Tarp et al., 2018						ns		
Bugge et al., 2012	ns/+[o]	ns			ns			
Resaland et al., 2011	ns							
Lazaar et al., 2007	ns	+						
Thivel et al., 2011	ns							
Weeks and Beck, 2012	ns/-[p]							
Sacchetti et al., 2013	+			ns				
Hart, 2014		ns		ns				
Hobin et al., 2017					ns			
Ten Hoor et al., 2018						ns		
Lucertini et al., 2013	ns							
Nogueira et al., 2017	Ns[q]							
Promotion of PA outside of PE classes (n = 8)								
Donnelly et al., 2009	ns				+	+		
Ford et al., 2013	ns					ns		
Harman, 2014		ns						
Azevedo et al., 2014)	+				–			
Farmer et al., 2017	ns	ns			ns/+[r]			
Benden et al., 2014						+		
Breheny et al., 2020		ns/+[s]						
Have et al., 2018	ns				ns	ns		
Changing foods/drinks sold and/or served (n = 3)								
Damsgaard et al., 2014		ns					ns	+
Schwartz et al., 2016		+		+/ns[t]				
Muckelbauer et al., 2009		ns		+				
Multicomponent interventions (n = 29)								
Llargues et al., 2011	+			ns			+	ns
Recasens et al., 2019	+							
Llargués et al., 2012	+							
Llargués et al., 2017	+							
Foster et al., 2008	ns	ns		+/ns[u]			ns	
Rappaport et al., 2013		ns		ns				
Parsons et al., 2014				ns				
Jansen et al., 2011	ns			+				
Kriemler et al., 2010	+				+	ns		
Meyer et al., 2014	ns				ns	ns		

(*continued on next page*)

Table 4 (*continued*)

First author, year, citation	Outcome measures							
	Adiposity outcome measures				PA outcome measures		Fruit and vegetable consumption	
	BMI	BMI z scores	BMI percentile	% overweight and/or obese	MVPA	Step-counts	fruit	vegetables
Hollis et al., 2016	+	ns/+[v]			ns			
Sutherland et al., 2016					+	+		
Story et al., 2012	ns	ns		+/ns[w]			ns	ns
Marcus et al., 2009				+		ns		
Santos et al., 2014)		ns				ns		
Spencer et al., 2014						+		
Bell et al., 2017					ns	+	ns	ns
Adab et al., 2018		ns/+[x]		ns	ns		ns	
Griffiths and Griffiths, 2019	ns		ns					
Aperman-Itzhak et al., 2018				+				
Bartelink et al., 2019)		+/ns[y]						
Ickovics et al., 2019			ns/+[z]					
Kennedy et al., 2018	ns	ns			ns			
Pablos et al., 2018	ns							
Dewar et al., 2013	ns	ns						
Lubans et al., 2012	+	+			ns	ns		
Yang et al., 2017	+	+/ns*		ns				
Weber et al., 2017	ns	ns			ns	ns		
Ariza et al., 2019				+**			ns	ns

"+" denotes positive effect on outcome; "ns" denotes non-significant effect on outcome; blank cells indicate outcome data was not measured or did not meet criteria.
[a]Increase in vegetable consumption according to the 24 h diary but not 3-day diary.
[b]ns for the total sample; + for girls.
[c]ns for the total sample; + for girls.
[d]ns for the total sample; + for girls.
[e]+ overall; ns for boys.
[f]ns overall; + for the low-SES community.
[g]+ in younger/ ns in older students.
[h]+ for the HSAT and MSBE interventions; ns for SNAK team.
[i]ns for incidence and prevalence of overweight/obesity at T1 and T2; negative results for prevalence of obesity at T2 in the intervention group.
[j]ns at T1; negative results at T2 (i.e., statistically significant increase and decrease in BMI z-scores were observed in the intervention and control groups, respectively).
[k]ns at the 4-year follow-up; + at 8-year follow-up.
[l]ns differences for the change between groups; statistically significant positive changes within groups.
[m]+ for elementary school girls; ns for elementary school boys and middle school students.
[n]+ in total sample of overweight and normal weight kids; ns in both groups when stratified by sex.
[o]ns changes in BMI from baseline to postintervention; + change from baseline to follow up.
[p]ns for boys; negative trend in girls.
[q]ns difference between T1-T2 and T2-T3 (results for T1-T3 not presented).
[r]ns in the 1st year; + in the second year.
[s]ns in the total sample and boys; + in girls.
[t]+ in the likelihood of being overweight; ns in being obese.
[u]+ on the incidence and prevalence of overweight; ns for the incidence, prevalence, and remission of obesity and remission of overweight.
[v]ns at 12 months; + at 24 months follow-up.
[w]+ for overweight; ns for obesity.
[x]ns at 15- and 30-month follow-up, but + at 39-month follow-up.
[y]+ for T1 and T2 for Partial HPSF vs control, for T2 for Full HPSF vs. control; ns for T1 for Full HPSF vs. control.
[z]ns for Year 1 and + for Year 2 and 3 post-intervention (nutrition intervention); ns at Year 1, 2, and 3 post-intervention (physical activity intervention).
*+ in the total sample, normal weight children, boys, and elementary school students; ns in overweight and obese, girls, and middle school students.
**the outcome of interest was cumulative incidence rate of obesity.

0.04), BMI z score (0.01, 95% CI: −0.04, 0.02), step counts per minute (1.24, 95% CI: −1.62, 4.09), and MVPA (2.16, 95% CI: −3.91, 8.23).

3.9. Changing foods/drinks sold and/or served in schools (n = 3)

No studies reported on PA outcomes of interest. Only one study (Damsgaard et al., 2014) measured FV intake, with positive effects reported only on vegetable intake. Two studies (Schwartz et al., 2016; Muckelbauer et al., 2009) reported significant changes in adiposity outcomes, and one study (Schwartz et al., 2016) reported mixed results on prevalence of overweight and/or obese.

Meta-analysis showed no overall difference of this type of intervention on BMI z score (−0.01, 95% CI: −0.02, 0.01) and odds of being obese (0.96, 95%CI: 0.88, 1.05) or overweight/obese (0.96, 95% CI: 0.86, 1.06). Data on FV intake was not enough to pool in the meta-analysis.

3.10. Multicomponent interventions (n = 29)

Six studies (Llargues et al., 2011; Foster et al., 2008; Story et al., 2012; Bell et al., 2017; Adab et al., 2018; Ariza et al., 2019) evaluated FV intake, and only one (Llargues et al., 2011) found significant positive effect on fruit intake. Two studies (Foster et al., 2008; Adab et al., 2018) reported no significant effect on combined FV consumption. Four (Sutherland et al., 2016) out of twelve studies showed significant positive effect on PA outcomes. Twelve (Jansen et al., 2011; Kriemler et al., 2010; Hollis et al., 2016; Marcus et al., 2009; Aperman-Itzhak et al., 2018; Bartelink et al., 2019; Lubans et al., 2012; Yang et al., 2017; Llargues et al., 2011; Recasens et al., 2019; Llargués et al., 2012; Llargués et al., 2017) of 25 studies measuring adiposity outcomes reported significant positive effects, and three studies (Foster et al., 2008; Hollis et al., 2016; Yang et al., 2017) reported mixed results based on the subgroup analysis.

Multicomponent interventions showed significant difference in BMI

Table 5
Summary results of the meta-analysis for the intervention effect by outcomes and the type of interventions.

Outcome (*units*) Program type	Number of Studies	Number of effect estimates	Effect [95% CI]
BMI*kg/m²*			
Comprehensive School Health approach	8	11	−0.26 [−0.40, −0.12]
Multicomponent interventions	16	22	−0.18 [−0.29, −0.07]
Modifications of the existing PE curriculum	10	16	−0.16 [−0.3, −0.02]
Promotion of PA outside of the PE classes	5	7	−0.18 [−0.39, 0.04]
Provision of healthy foods in schools	1	2	−0.33 [−0.94, 0.28]
z score			
Comprehensive School Health approach	9	12	−0.02 [−0.04, 0.01]
Multicomponent interventions	12	21	−0.04 [−0.06, −0.01]
Modifications of the existing PE curriculum	4	8	0.00 [−0.06, 0.06]
Promotion of PA outside of the PE classes	3	5	−0.01 [−0.04, 0.02]
Changing foods/drinks sold and/or served in schools	3	4	−0.01 [−0.02, 0.01]
Universal school food program	2	4	0.05 [−0.05, 0.15]
percentile			
Multicomponent interventions	2	7	−0.8 [−1.49, −0.10]
Modifications of the existing PE curriculum	3	6	−0.68 [−1.42, 0.06]
Provision of healthy foods in schools	2	2	−7.92 [−16.53, 0.7]
Overweight *(odds)*			
Comprehensive School Health approach	2	2	0.89 [0.58, 1.38]
Multicomponent interventions	2	2	0.65 [0.49, 0.86]
Obesity *(odds)*			
Comprehensive School Health approach	4	4	0.84 [0.64, 1.12]
Multicomponent interventions	3	3	0.79 [0.51, 1.22]
Modifications of the existing PE curriculum	2	2	0.85 [0.51, 1.41]
Changing foods/drinks sold and/or served in schools	1	2	0.96 [0.88, 1.05]
Universal school food program	1	2	1.25 [0.94, 1.66]
Overweight/Obese *(odds)*			
Comprehensive School Health approach	3	4	0.85 [0.71, 1.01]
Multicomponent interventions	5	6	0.84 [0.65, 1.08]
Modifications of the existing PE curriculum	2	2	0.41 [0.23, 0.73]
Changing foods/drinks sold and/or served in schools	2	3	0.96 [0.87, 1.06]
Universal school food program	1	2	1.21 [0.95, 1.55]
Step counts*per day*			
Comprehensive School Health approach	2	2	1155.76 [449.77, 1861.75]
Multicomponent interventions	3	4	−0.06 [−1.02, 0.90]
per minute			
Comprehensive School Health approach	2	2	20.70 [−46.23, 87.63]
Multicomponent interventions	5	5	0.27 [−0.41, 0.95]
Modifications of the existing PE curriculum	2	2	10.5 [−63.81, 84.81]
Promotion of PA outside of the PE classes	4	6	1.24 [−1.62, 4.09]
MVPA *(minutes per day)*			
Comprehensive School Health approach	3	4	−0.67 [−4.39, 3.05]
Multicomponent interventions	8	10	0.18 [−0.51, 0.87]
Modifications of the existing PE curriculum	2	2	−1.47 [−3.4, 0.46]
Promotion of PA outside of the PE classes	4	5	2.16 [−3.91, 8.23]
Fruit *(servings or times per day)*			
Comprehensive School Health approach	4	5	0.13 [0.04, 0.23]
Modifications of school nutrition policies	1	3	0.30 [0.1, 0.51]
Vegetables *(servings or times per day)*			
Comprehensive School Health approach	4	5	0.12 [−0.01, 0.25]
Modifications of school nutrition policies	1	3	−0.02 [−0.1, 0.06]

Note: Subgroups that did not have at least 2 effect estimates are not shown.
§ Effect sizes are listed for the following outcomes (units of measures are listed in brackets): BMI (kg/m^2, z score, percentile), overweight and obesity (odds for overweight, obesity, or both), step counts (per day, per minute), MVPA (minutes per day), fruit (servings or times per day), and vegetables (servings or times per day).

(−0.18, 95% CI: −0.29, −0.07), odds of being overweight (0.65, 95% CI: 0.49, 0.86), BMI z score (−0.04, 95% CI: −0.06, −0.01), BMI percentile (−0.8, 95% CI: −1.49, −0.1), but no difference in the odds of being obese (0.79, 95%CI: 0.51, 1.22) or overweight/obese (0.84, 95% CI: 0.65, 1.08), step-counts per day (−0.06, 95% CI: −1.02, 0.9) and per minute (0.27, 95% CI: −0.41, 0.95), and MVPA (0.18, 95% CI: −0.51, 0.87). Data was insufficient to perform meta-analysis on FV intake.

3.11. Publication bias

Based on the results of visual inspection of funnel plots and the regression-based Egger test for small-study effects (Supplementary Fig. S3), there is evidence suggesting potential publication bias for vegetable intake ($p = 0.043$) and odds of overweight and obesity ($p = 0.006$). However, we could not perform “trim and fill” analysis due to a small number of studies within each group of interventions, and therefore the pooled estimates obtained for these outcomes should be interpreted with caution.

4. Discussion

This systematic review with meta-analysis of effectiveness of school-based interventions focusing on preventing obesity and underlying lifestyle risk factors, was informed by facilitated group discussions among knowledgeable stakeholders who identified intervention types perceived as feasible, acceptable and sustainable in the Canadian context (Montemurro et al., 2018). Among the 83 selected papers, the three most common types of interventions were those utilizing a CSH approach, modifications to existing PE curricula, and those with multiple components. While stakeholders identified universal school food programs and modifications of school nutrition policies as top priority interventions, very few studies fulfilling the inclusion criteria with extractable data were found. This finding illustrates the discrepancy between available evidence and evidence required to guide decision-making. To facilitate policy decisions related to school-based interventions, we encourage local policy-makers and stakeholders to engage with researchers when identifying, implementing, and evaluating interventions.

The CSH interventions and modifications of school nutrition policies had sufficient data on *FV intake,* allowing meta-analysis. Both interventions showed statistically significant positive effects on fruit intake, as opposed to not statistically significant effect on vegetable intake. This finding aligns with available evidence demonstrating preference for fruits (Perry et al., 2004) and the practicality of eating fruits as snacks (Bjelland et al., 2015).

CSH interventions showed statistically significant effect on step-count per day, but not on step-count per minute. None of the other three types of interventions showed statistically significant effect on *PA outcome measures*. Potential explanations related to the measurement of PA include social desirability bias if questionnaires are used; non-compliance with wearing devices (Meyer et al., 2014) and considerable drop out due to data collection fatigue (Spencer et al., 2014); and the inability of certain devices to accurately measure specific activities (e.g., free play activities (Farmer et al., 2017). Moreover, there could be seasonal variations in PA patterns (Santos et al., 2014 1) and comparatively high PA in the study sample at baseline (Farmer et al., 2017). Potential explanations may include the lack of engagement of students and teachers at the intervention design stage, with subsequent implementation challenges. For example, similarly to Breheny et al. (2020) and Griffiths and Griffiths (2019), a recent study in 53 primary schools in the UK showed no significant effects of the intervention combining healthy eating and PA on any of the anthropometric, dietary, physical activity and psychological outcomes due to the fidelity of the program being compromised by a considerable lack of both compliance to the intervention protocol and teachers involvement due to competing demands (Adab et al., 2018).

Meta-analysis showed that multicomponent, CSH approach-based, and modifications of the PE curricula are effective in improving *obesity outcomes*. These intervention types usually require approval and support of school system leaders promoting school-wide changes that may be better embedded, and in the case of PE curricula, often compulsory (Connelly et al., 2007). However, as Hollis et al. (2016) noted, changes in adiposity outcomes might not be clinically significant at the individual level, but can still produce health benefits at the population level. In fact, even small changes in BMI z scores can point to a change in the increasing BMI trend typical for children and youth (Bartelink et al., 2019), and slowing this trend is critically important for prevention of obesity later in life (Goldschmidt et al., 2013).

There are certain limitations of the included studies that warrant discussion. While the majority of the studies utilized a cluster RCT design with comparatively large number of students, most often the number of schools that were randomized into each arm was small (Sahota et al., 2001), which could result in the overestimation of the intervention effect (Waters et al., 2018). Allocation concealment and masking of participants and assessors were impossible in all but one study (Thivel et al., 2011), considering that interventions were too "obvious" (Jansen et al., 2011). Control schools could not be forbidden to implement any interventions due to ethical concerns (De Coen et al., 2012; Alaimo et al., 2013), and intervention schools could modify interventions, leading to heterogeneity of intervention activities and their delivery and different levels of intervention dose (Millar et al., 2011; Breheny et al., 2020). Moreover, as was mentioned above, effectiveness of interventions when implemented in the real-world setting is often less than efficacy shown in RCTs, where interventions are often delivered by knowledgeable and skilled experts (McCrabb et al., 2019). Quasi-experimental studies were prone to selection bias: underrepresented children tended to be overweight and obese (Grydeland et al., 2014; Millar et al., 2011), with migrant background (Meyer et al., 2014), and with low SES (De Coen et al., 2012). Most of the studies assessed effectiveness shortly or right after the end of the intervention. However, interventions might "serve as 'catalyst' to prolonged habitual changes" (Maziekas et al., 2003) and significant long-term, despite non-significant short-term, effects were observed in several studies (Bere et al., 2014; Bugge et al., 2012; Farmer et al., 2017; Hollis et al., 2016).

While we focused on particular outcomes with the overarching goal to inform future economic modelling, the selected outcomes had certain pitfalls. For example, dietary assessment in children, especially when completed by parents who might not be aware of what their children eat at school (De Coen et al., 2012), appears imprecise. De Coen et al. (2012) hypothesized that eating behaviours could have changed for the better during school hours, and therefore were not captured and assessed using parental questionnaires. Use of parental questionnaires to assess PA might also be subjective and prone to bias (Vander Ploeg et al., 2014), just as well as measuring PA only during the school day (Spencer et al., 2014). BMI as the primary measure for adiposity in children has also been criticized as it cannot change significantly over short periods of time (Sahota et al., 2001) and depends on weight and height with no regard for the distribution of fat mass (Weeks and Beck, 2012). Similarly, BMI z scores have low specificity, particularly in obese children and youth: in fact, Freedman et al. (2017) showed that BMI z score values could differ by more than one standard deviation simply because of differences in age or sex. A recent longitudinal observational study in 515 obese children corroborated findings of low specificity (42%) of BMI z score for predicting a decrease in % body fat, thus highlighting the limitations of using BMI z scores alone to monitor changes in adiposity (Vanderwall et al., 2018). Despite this criticism, BMI for age is the most established diagnostic measure for childhood obesity. As Reilly (2006) noted, most of the currently used cutoffs appear adequate for using BMI in clinical practice and research. BMI is an inexpensive and easy-to-perform measure that correlates directly with body fat measurements (Reed et al., 2013) and appears to be the most feasible screening tool in the multifaceted approach to childhood obesity prevention (Parsons et al., 2014). The use of alternative BMI metrics, such as distance and % distance from median (including that on a log scale), has recently been proposed as those suitable for assessing BMI in all children, including overweight and obese (Freedman).

Several strengths and limitations need to be acknowledged. We conducted a comprehensive search of both peer-reviewed and grey literature. However, we focused on specific outcomes to keep the meta-analysis feasible. Further, some heterogeneity remained, which was particularly pronounced in multicomponent interventions that could contain any combination of intervention components, as long as at least one of them was prioritized. Hence, random-effects models were used to pull the results of the interventions together. Finally, it needs to be highlighted that, despite an innovative approach we took, the focus of this systematic review was on the *effectiveness* of school-based intervention types, prioritized by the *perceived* feasibility, acceptability and sustainability that emerged in facilitated discussions rather than detailed evaluation. While some may consider this a limitation, we view it as an innovative strategy to overcome the gaps in literature: future studies should include process evaluation measures to complement assessment of intervention effectiveness. Prioritization was guided by the Canadian context, and therefore generalization of our findings beyond Canada should proceed with caution. Nevertheless, our approach of identifying prioritized interventions can be freely adopted to other countries.

5. Conclusion

Among the papers identified in the review, only two were classified as universal food programs and one as modifications of school nutrition policies, thus highlighting the mismatch between the available research and required evidence to inform decision-making. Interventions based on the CSH approach and modifications of school nutrition policies showed positive effect on fruit intake, but not on vegetable intake. CSH interventions showed statistically significant positive effect on step-count per day, but not per minute; none of the other interventions appeared beneficial in terms of their effect on PA outcome measures. CSH-based, multicomponent, and interventions that consisted of modifications of the PE curricula appear effective in improving obesity outcomes.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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