

Obesity Prevention Interventions and Implications for Energy Balance in the United States and Mexico: A Systematic Review of the Evidence and Meta-Analysis

Andrea S. Richardson¹, Christine Chen², Roland Sturm^{3,4}, Gulrez Azhar², Jeremy Miles⁵, Jody Larkin^{6,7}, Aneesa Motala^{6,7}, and Susanne Hempel^{6,7}

Objective: Obesity is preventable and yet continues to be a major risk factor for chronic disease. Multiple prevention approaches have been proposed across multiple settings where people live, work, learn, worship, and play. This review searched the vast literature on obesity prevention interventions to assess their effects on daily energy consumed and energy expended.

Methods: This systematic review (PROSPERO registration CRD42017077083) searched seven databases for systematic reviews and studies reporting energy intake and expenditure. Two independent reviewers screened 5,977 citations; data abstraction supported an evidence map, comprehensive evidence tables, and meta-analysis; critical appraisal assessed risk of bias; and the quality of evidence was evaluated using Grading of Recommendations Assessment, Development and Evaluation (GRADE).

Results: Hundreds of published reviews were identified. However, few studies reported on energy intake and expenditure to determine intervention success. Ninety-nine studies across all intervention domains were identified. Few areas demonstrated statistically significant effects across studies; school-based approaches and health care initiatives reduced energy consumed, education reduced energy consumed and increased energy expended, and social-group approaches increased energy expenditure.

Conclusions: Despite the amount of research on obesity prevention interventions, very few studies have provided relevant information on energy intake and expenditure, two factors determining weight gain. Future research needs to fill this gap to identify successful public health policies.

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Introduction

Estimated global obesity prevalence doubled from 1980 to 2008 (1,2). In the United States, obesity prevalence has reached 35% in men, 40% in women (3), and 17% in children (4); severe obesity may still be increasing (5,6). The U.S. National Institutes of Health has provided approximately \$9.5 billion to obesity prevention and intervention research over the past decade (7). While much work has been done in clinical and educational interventions, dietary and physical activity patterns are influenced by environments. The Foresight Programme used a mapping approach, indicating that obesity is likely determined by a complex multifaceted system with multiple drivers (8). As researchers recognize different obesogenic environmental determinants, numerous distinct research subfields have been launched. Putting a multitude

of isolated data points into a coherent picture is challenging but necessary to assess whether proposed solutions are promising or not. There is a need for a cohesive thread to understand findings across subfields because eventually preventing obesity requires changes in either energy intake or energy expenditure.

This review searched the literature on obesity prevention interventions to assess their effects on daily energy consumed and energy expended. We assessed evidence across approaches that are being tested and implemented in public health areas in the United States and Mexico. Focusing on a few would ignore the myriad of ways that changes in economic, physical, and social environments can impact obesity. We included studies of food labeling, fiscal measures, physical environment and transportation, food supply and lifestyle commodities, work

¹ Behavioral and Policy Sciences, RAND Corporation, Pittsburgh, Pennsylvania, USA. Correspondence: Andrea Richardson (arichard@rand.org) ² Pardee RAND Graduate School, Santa Monica, California, USA ³ Economics, Sociology, and Statistics, RAND Corporation, Santa Monica, California, USA ⁴ RAND Health, Santa Monica, California, USA ⁵ Google, Inc., Los Angeles, California, USA ⁶ Southern California Evidence-Based Practice Center, RAND Health Care, Santa Monica, California, USA ⁷ University of Southern California, Los Angeles, California, USA.

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site interventions, population-based health care initiatives, school-based interventions, education and public health campaigns, and social-group approaches. We focused on obesity prevention strategies aimed at general populations. We summarized effectiveness in meta-analyses to determine intervention effects, and formal quality-of-evidence assessments provided a comprehensive overview.

Methods

The systematic review protocol is registered in PROSPERO (CRD42017077083). We chose intervention categories in order to parameterize a microsimulation model of obesity policies that incorporates energy balance and the interplay between diet and physical activity in the development of obesity.

Data sources and searches

We searched PubMed (biomedical literature), Cochrane Database of Systematic Reviews (Cochrane Collaboration reviews of health interventions), CAB (applied life sciences), ERIC (education research), Cumulative Index to Nursing and Allied Health Literature, Campbell Systematic Reviews (Campbell Collaboration reviews addressing social and economic topics), and Web of Science (multidisciplinary scientific research collection). The search strategy is documented in Supporting Information Table S1, and it combined known diet and physical activity interventions and general search terms to identify novel approaches.

The search identified systematic reviews and primary research studies with concurrent or historic comparators to estimate effects of obesity prevention approaches. Systematic reviews provided comprehensive summaries of the literature for defined topics by combining thorough and comprehensive searches and synthesis of the available evidence. Searches built on a comprehensive review by the World Health Organization of studies evaluating diet and/or physical activity interventions for children and/or adults published in 2009 (9), and updated searches targeted studies not yet summarized in the World Health Organization review.

Study selection

The eligibility criteria are documented in a population, intervention, comparator, outcome, timing, setting, and study design framework (Supporting Information Table S2). Two independent reviewers screened publications; disagreements were resolved through discussion.

Data abstraction and critical appraisal

Data were abstracted by a systematic reviewer and checked for accuracy by a second reviewer. We abstracted the reported daily calorie intake and daily energy expenditure in the intervention and the comparator group. We assessed selection bias and confounding, performance bias, detection bias, attrition bias, and other sources of bias. The results of the risk of bias assessments were incorporated into the quality of evidence summary. The critical appraisal criteria and results are presented in Supporting Information Figure S1.

Obesity prevention intervention categories

We categorized interventions according to their primary aim using mutually exclusive categories (see Supporting Information Table S3).

Data synthesis and analysis

The evidence synthesis was based on primary research studies that report on energy consumed and/or energy expended. In addition, we provided an evidence map to document the published systematic reviews on the topic. The systematic reviews were used to provide a broader overview of the existing literature and as a source to identify primary research studies.

We converted intervention effects to standardized mean differences (SMD) together with the 95% CIs in order to compare effects across individual studies. Studies exclusively targeting children were analyzed separately from studies addressing adults only or children and adults. We stratified studies with concurrent comparators (e.g., controlled trials) and those with historic comparators (e.g., pre-post evaluations). Where a sufficient number of studies was available, we conducted sensitivity analyses to test the robustness of the intervention effect estimates. Meta-analysis was based on random-effects models using the Hartung-Knapp correction.

The quality of evidence was assessed for each summary statement using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach. The initial assessment for the quality of evidence was based on study design. Randomized controlled trials (RCTs) comparing an intervention to a concurrent comparator start at high quality of evidence, whereas studies with historic comparators start at low quality of evidence. Eight criteria were used to assess the quality of the evidence. Five criteria were used to downgrade where applicable (study limitations, inconsistency, indirectness, imprecision, and publication bias), and three criteria (presence of a large effect, documented dose-response relationship, and residual confounding would reduce the effect) were used to potentially upgrade the quality of evidence. We categorized our confidence in the summary as high, moderate, low, or very low using the GRADE criteria.

Results

We identified 5,977 citations and obtained 1,565 publications. We identified 99 unique studies and 338 systematic reviews meeting the inclusion criteria. The literature flow diagram is in Supporting Information Figure S2, and we include a list of the included systematic reviews (Supporting Information Table S4).

We identified a large number of systematic reviews. Figure 1 shows the distribution of topics addressed in published reviews, and they are described in Supporting Information Table S5.

The 99 primary research studies reporting on energy consumption and/or expenditure are documented in a detailed evidence table in Supporting Information Table S6. The table is stratified by obesity prevention approach and provides a comprehensive overview. The results across studies are summarized in the Table 1, which documents the presence and absence of evidence for all intervention categories of interest, the number of studies per intervention, the study design the results are based on, and the summary across studies. The following provides a synthesis for the different obesity prevention strategies across the identified evidence. Citations and review or study details are documented in Supporting Information Table S6.

Food labeling

We identified 69 systematic reviews in which the scope of the review included food-labeling initiatives. Six of these exclusively addressed

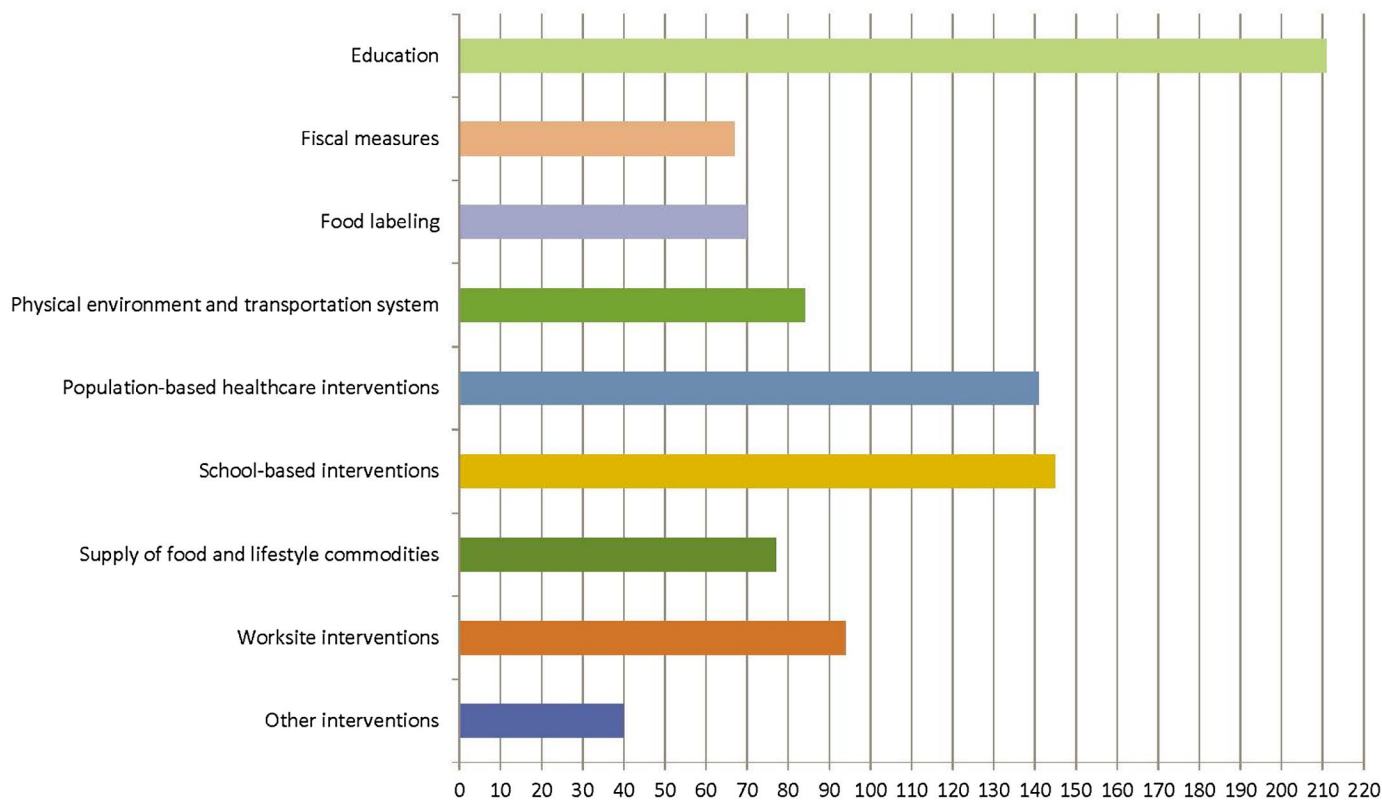


Figure 1 Overview of interventions targeted in published systematic reviews. [Color figure can be viewed at wileyonlinelibrary.com]

food labeling such as calorie labeling in restaurants. The reviews reported on a variety of acceptability outcomes and obesity measures.

We did not identify any individual study that met inclusion criteria and reported on daily energy consumed or expended with food-labeling initiatives.

Financial incentives

We identified 68 systematic reviews in which the scope of the review included financial incentives. Of these, six exclusively targeted financial incentives.

Our literature searches in databases and reference mining of the systematic reviews identified one relevant study that reported on daily energy consumed.

Energy consumed. The study evaluated whether incentivizing the purchase of fruits and vegetables and prohibiting the purchase of less nutritious food in a food-benefit program improves the nutritional quality of participants’ diets. The study reported reduced intake of energy (−96 kcal per day; SE, 59.9), but the difference between the intervention and control group was not statistically significant (SMD, 0.10; 95% CI: −0.24 to 0.44; one RCT) (10). The quality of the evidence was downgraded because the result is based on a single study and the consistency across studies could not be assessed.

None of the identified studies reported on children alone.

Energy expended. None of the identified studies reported on energy expended.

Physical environment and transportation system

We identified 83 systematic reviews that covered physical environment interventions. Four of the systematic reviews exclusively addressed physical environment changes and transportation system approaches.

Two studies reporting on physical environment interventions met inclusion criteria, and both reported on energy consumed.

Energy consumed. One of the studies assessed the effect of introducing a supermarket in a “food desert” on daily calorie intake compared with participants in a comparison neighborhood (11). The study reported a decrease in the intervention group; however, the study reported no measure of dispersion, and therefore the effect size could not be calculated. The other study assessed the impact of a new government-subsidized supermarket on children’s dietary intake (12). Dietary recall data showed more calories consumed in the intervention group (SMD, 0.41; 95% CI: 0.14-0.69; one cohort study), and the authors concluded that further research is needed to determine whether healthy food retail expansions can improve food choices of children and their families. Given the inconsistent findings in the small number of studies, the quality of evidence was downgraded to very low quality.

Energy expended. We did not identify studies reporting on energy expended.

TABLE 1 Summary of findings

Intervention outcome	Number of studies and study design	Reason for downgraded quality	Effect estimate and direction of effects	GRADE
<i>Food labeling</i>				
Energy consumed	None	NA	NA	NA
Energy expended	None	NA	NA	NA
<i>Fiscal measures</i>				
Energy consumed	1 RCT	Consistency could not be assessed, study limitations	No statistically significant difference (SMD, 0.10; 95% CI: -0.24 to 0.44)	Very low
Energy expended	None	NA	NA	NA
<i>Physical environment and transportation</i>				
Energy consumed	1 CT 1 cohort study	Inconsistency	ES could not be calculated for the CT (but favored the intervention group); the control group had lower intake in the cohort study (SMD, 0.41; 95% CI: 0.14 to 0.69; 1 cohort study)	Very low
Energy expended	None	NA	NA	NA
<i>Supply of food and lifestyle commodities</i>				
Energy consumed	3 RCTs 1 CT	Inconsistency, study limitations	RCTs report positive but not statistically significant differences (SMD, -0.23; 95% CI: -0.45 to -0.00; 3 RCTs); the CT reported insufficient data	Low
Energy expended	None	NA	NA	NA
<i>Work-site interventions</i>				
Energy consumed	2 RCTs 1 CT 1 pre-post study	Inconsistency, study limitations	2 studies reported positive results, but ES could not be computed; 2 studies reported conflicting results and were based on diverse study designs (SMD, -0.20; 95% CI: -0.53 to 0.13; 1 RCT; SMD, -0.98; 95% CI: -1.32 to -0.65; 1 pre-post study)	Very low
Energy expended	6 RCTs 1 CT 2 pre-post studies	Inconsistency, imprecision	4 RCTs found no statistically significant difference (SMD, 0.22; 95% CI: -0.17 to 0.61; 4 RCTs); 2 pre-post studies reported improvements but could not be combined in a summary estimate	Low
<i>Population-based health care initiatives</i>				
Energy consumed	15 RCTs	Inconsistency (sensitivity analysis)	Reduced consumption (SMD, -0.13; 95% CI: -0.18 to -0.08; 9 RCTs)	Moderate
Energy consumed, children only	2 RCTs	Imprecision	No statistically significant difference (SMD, -0.19; 95% CI: -0.61 to 0.24; 2 RCTs)	Low
Energy expended	5 RCTs	Study limitations, inconsistency	Studies could not be combined; effect varied	Very low
<i>School-based interventions</i>				
Energy consumed, children	10 6 RCTs 3 CTs 1 cohort study	Inconsistency	Significant reduction (SMD, -0.11; 95% CI: -0.19 to -0.04; 6 studies)	Moderate

TABLE 1. (continued).

Intervention outcome	Number of studies and study design	Reason for downgraded quality	Effect estimate and direction of effects	GRADE
Energy expended, children	5 RCTs 1 CT 2 pre-post studies	Inconsistency	No systematic effect (SMD, -0.08; 95% CI: -0.65 to 0.49; 6 trials)	Low
<i>Health education campaigns</i> Energy consumed	17 RCTs 3 pre-post studies	Inconsistency	RCTs showed a statistically significant effect (SMD, -0.17; 95% CI: -0.26 to -0.08; 10 RCTs); pre-post studies both positive but could not be combined	Moderate
Energy consumed, children only Energy expended	3 RCTs 13 RCTs 2 pre-post studies	Inconsistency, imprecision Inconsistency	SMD, -0.20; 95% CI: -0.41 to 0.01; 3 RCTs Positive pooled effects but individual results varied (SMD, 0.37; 95% CI: 0.07 to 0.67; 10 RCTs; SMD, 0.48; 95% CI: 0.16 to 0.79; 2 pre-post studies)	Very low Low
Energy expended, children only	2 RCTs	Inconsistency, imprecision	Difference not statistically significant (SMD, 0.06; 95% CI: -0.41 to 0.52; 2 RCTs)	Very low
<i>Social-group approaches</i> Energy consumed	2 RCTs 1 CT	Inconsistency, imprecision	Studies could not be combined; conflicting results	Very low
Energy expended	7 RCTs 1 CT	Inconsistency	Statistically significant increase (SMD, 0.26; 95% CI: -0.07 to 0.44; 8 trials)	Moderate
Energy expended, children only	1 pre-post study 3 RCTs	Imprecision	Not statistically significant (SMD, 0.17; 95% CI: -0.17 to 0.51; 3 RCTs)	Low

CT, controlled trial; ES, effect size; NA, not applicable; RCT, randomized controlled trial; SMD, standardized mean difference.

Supply of food and lifestyle commodities

Of all identified systematic reviews, 76 included interventions that involved supply of food or lifestyle commodities. Of these, six addressed only supply of food (e.g., diet approaches with pre-prepared food) or product placement (e.g., changing shops and supermarkets to promote healthier options).

Four studies met inclusion criteria, and all reported on daily energy intake. The details of each of the studies are documented in Supporting Information Table S6 and summarized in this section.

Energy consumed. An RCT evaluated the effects of health coaches targeting the home food and activity environment compared with families receiving only educational material (13). A second RCT evaluated the effect of a 1-year intervention of home delivery of noncaloric beverages (14). An RCT delivered in Mexico provided women with overweight with bottled water for 9 months to increase water intake compared with a group receiving education alone (15). The pooled school-based result showed a small treatment effect showing a statistically significant reduction compared with control (SMD, -0.23 ; 95% CI: -0.45 to 0.00 ; three RCTs) (Supporting Information Figure S3). I^2 estimated no heterogeneity. Restricting to US studies did not substantially change the effect estimate but increased the CI so that the effect was not statistically significant (SMD, -0.26 ; 95% CI: -0.99 to 0.48 ; two RCTs).

A further study could not be combined with the RCTs (Supporting Information Table S7).

The quality of the evidence was downgraded to low quality because of inconsistency and study limitation. Only one of the three studies reported a statistically significant effect, and excluding one study resulted in no statistically significant effect.

Energy expended. None of the studies reported a measure of energy expended.

Work site interventions

Ninety-four of the identified systematic reviews included work site intervention evaluations. Fourteen of these reviewed only work site interventions.

Ten primary research studies met all inclusion criteria. Studies addressed a range of interventions implemented in the work site context. The individual studies are described in detail in Supporting Information Table S6.

Energy consumed. Four of the work site studies reported on daily energy consumption. The studies were difficult to combine, and it was not possible to estimate a summary effect across studies. An RCT evaluating a work site chronic disease prevention program reported no statistically significant differences between intervention and control groups (SMD, -0.20 ; 95% CI: -0.53 to 0.13 ; one RCT) (16). A second study compared two active interventions without a control group (17). The study reported no difference between the two interventions. The study indicated improvement in energy intake at follow-up; however, the effect size could not be computed because the study did not report the standard error (SE) of the difference (or provide the information that allowed it to be calculated). The third study evaluated the program America on the Move implemented as a research study at a

university (18). The study reported a positive effect on participants during the intervention week (SMD, -0.98 ; 95% CI: -1.32 to -0.65 ; one pre-post study). The fourth study was a cluster RCT evaluating an obesity prevention intervention for metropolitan transit workers (19). The study reported insufficient detail to compute an effect size.

The quality of the evidence for work site interventions on energy consumed was downgraded to very low quality because of inconsistency and study limitations that prevented estimating a summary effect.

Energy expended. Nine of the work site studies reported on energy expenditure. Four RCTs reported effect size estimates compared with a passive control group and were combined in a meta-analysis. The studies evaluated an activity monitoring interventions for physicians in training (20), a walking program for employees (21), booster breaks and physical activity computer prompts (22), and a work site chronic disease prevention program (16). Although three studies favored the intervention, only one reported a statistically significant improvement. The difference between intervention and control groups was not statistically significant across studies (SMD, 0.22 ; 95% CI: -0.17 to 0.61 ; four RCTs) (Supporting Information Figure S4). Two additional RCTs and a controlled trial could not be included in the analysis (insufficient data, comparative effectiveness); the studies are described in Supporting Information Table S7.

Two pre-post studies could be combined in a meta-analysis to estimate the effect of the intervention to the status before the intervention (18,23). The studies evaluated an implementation of the America on the Move program at a university (18) and an intervention to increase walking for women at rural work sites (23). Although both studies reported positive effects of the intervention, the effect size estimates varied so widely that a pooled effect showed a wide CI that did not support a statistically significant summary estimate. In addition, the width of the CI did not indicate that a summary estimate is meaningful.

Based on RCT evidence, work site interventions did not have a statistically significant effect on energy expended compared with concurrent control groups. However, the quality of the evidence was downgraded to low because of inconsistency and imprecision, and it remains unclear whether work site interventions do have an effect on energy expended.

Population-based health care interventions

We identified 139 systematic reviews that included health care interventions in their scope. Of these, 23 focused exclusively on health care interventions such as prevention programs implemented in primary care.

Sixteen studies in total met inclusion criteria. The studies recruited participants through health care settings (Supporting Information Table S6).

Energy consumed. All but three of the included studies reported on energy consumed. Nine RCTs assessed the effectiveness of the intervention compared with no intervention or other passive control groups. Interventions were described as dietary modification (24), using weight loss strategies from successful weight losers (25), culturally tailored lifestyle intervention (26), behavioral intervention for postpartum weight loss (27), internet-based program for low-income postpartum women (28), clinic-based weight management program (29), health behavior intervention for adolescents (30), mentorship model for urban adolescents (31), and tailored lifestyle modification (32). Across studies, health care interventions resulted in

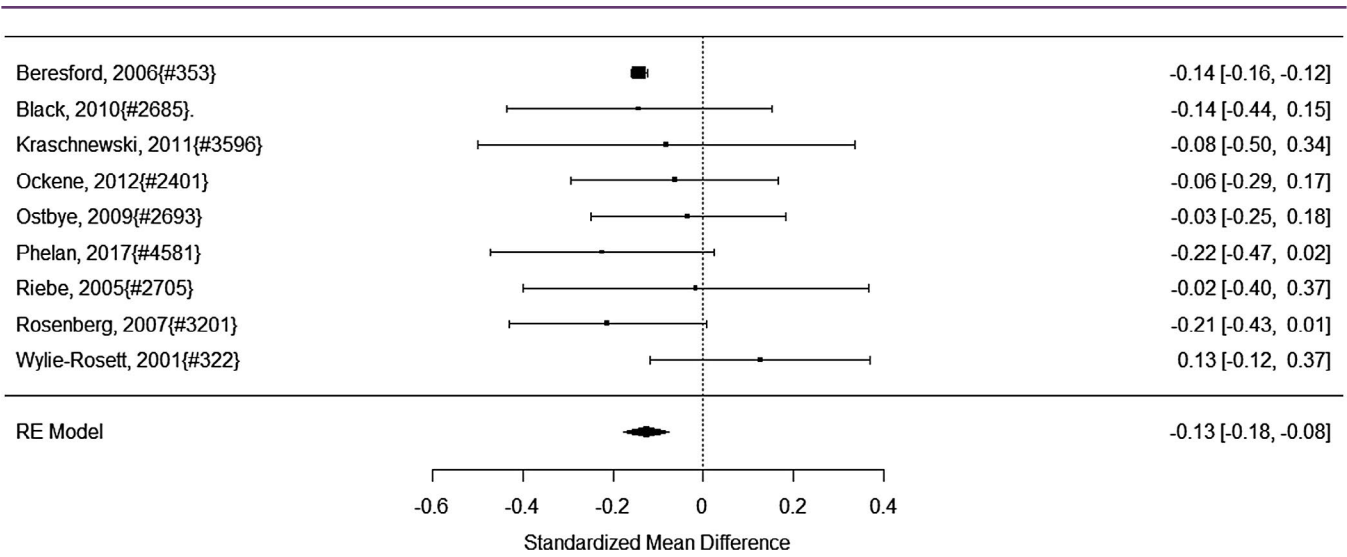


Figure 2 Estimated effects of population-based health care interventions on energy consumed.

a small effect favoring the interventions (SMD, -0.13; 95% CI: -0.18 to -0.08; nine RCTs) (Figure 2). The majority of studies reported a positive effect, although only one individual study was statistically significant. Effect estimates varied somewhat, but all CIs overlapped and I^2 was negligible (7%). There was no evidence of publication bias (Begg $P=0.90$, Egger $P=0.27$). Excluding Beresford et al. (24) in a sensitivity analysis showed that the result was primarily driven by this large study; the estimate without the study was not statistically significant (SMD, -0.09; 95% CI: -0.19 to 0.02; eight RCTs).

Two of the studies included children (30,31). A subgroup analysis for these found a similar effect estimate, albeit not statistically significant (SMD, -0.19; 95% CI: -0.61 to 0.24; two RCTs).

Several studies assessed the comparative effectiveness of different interventions; these are described in Supporting Information Table S7.

We judged the quality of evidence to be moderate for a small effect on reduced energy consumed (downgraded because of inconsistency across studies).

Energy expended. Five studies reported on energy expended. Two studies had passive control groups that allowed estimating the intervention effect. One RCT evaluated the effect on a mentorship model among urban, black adolescents (31). A cluster RCT investigated an internet-based program for low-income postpartum women (28).

The two studies reported very different results, one favoring the intervention and one the control group, indicating that a combined effect estimate is not appropriate (SMD, 0.02; 95% CI: -1.93 to 1.98; two RCTs). Two health care studies reported comparative effectiveness data, and one reported insufficient data (Supporting Information Table S6).

The quality of evidence was rated very low (downgraded for study limitations and inconsistency) because it was not possible to determine

with confidence whether health care interventions increased expended energy.

School-based interventions

A large number ($n=145$) of the identified systematic reviews included school interventions in their scope. Of these, 32 focused exclusively on school-setting interventions for various age groups (childcare setting to high school).

We identified 22 studies in schoolchildren that met inclusion criteria.

Energy consumed. Ten of the 22 studies reported on energy consumed. Figure 3 shows six trials that could be combined in a meta-analysis for the outcome energy consumed. One cluster RCT compared a multicomponent intervention for American Indian schoolchildren with no intervention (33). Casazza et al. (34) focused on the method of delivery of nutrition and physical activity information for adolescents in a nonrandomized investigator-controlled trial (compared with no intervention). A cluster RCT assessed a multicomponent intervention-based school intervention to prevent obesity compared with control schools (35). An additional cluster RCT for high schools compared nurse-delivered cognitive-behavioral counseling plus after-school exercise with information alone (36). A (nonrandomized) trial evaluated the effects of a cooking program for fifth graders (37). A natural experiment assessed the effect of state laws governing fat, sugar, and caloric content of foods sold in schools (38). The interventions varied in duration, ranging from 3 months (34) to 3 years (33). Across studies, we found a small effect in these school interventions compared with no intervention or information only (SMD, -0.11; 95% CI: -0.19 to -0.04; six studies) (Figure 3). I^2 was negligible (10%); however, one study (37) came to a different effect estimate than the other studies (the CIs did not overlap). There was no evidence of publication bias (Begg $P=0.48$, Egger $P=0.43$). Four RCTs could not be pooled with the others (Supporting Information Table S7).

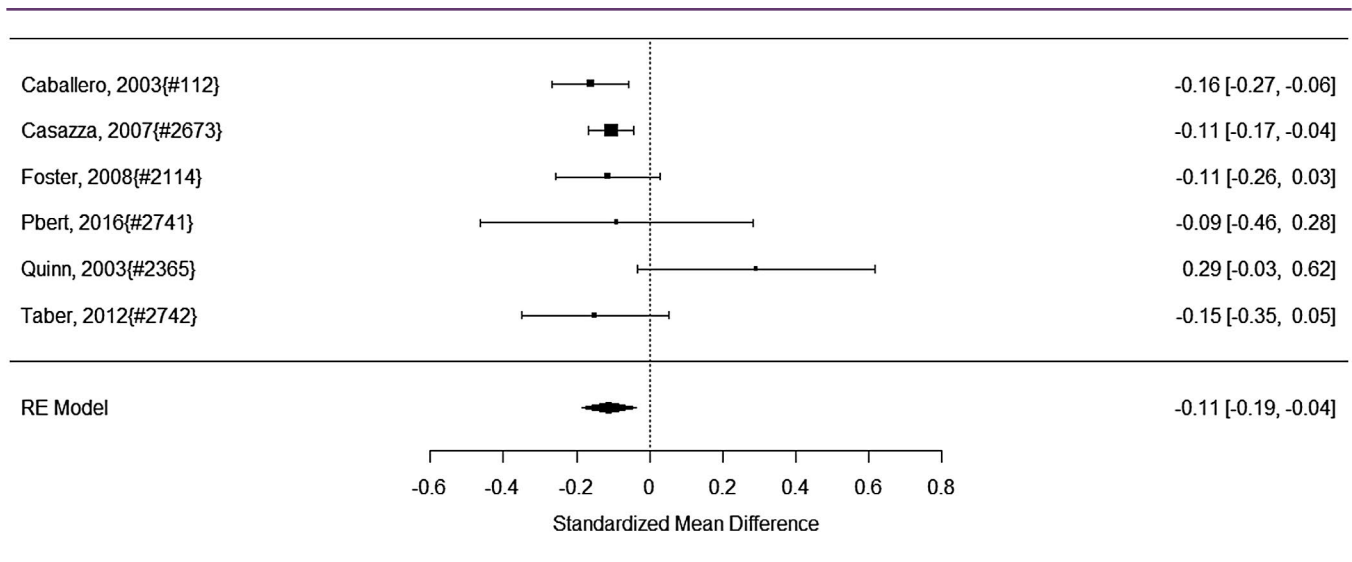


Figure 3 Estimated effects of school-based initiatives on energy consumed.

All studies addressed the effects of the intervention on children and none on adults.

The quality of evidence was determined to be moderate that school interventions have a small effect on daily energy consumed (downgraded because of inconsistency).

Energy expended. Twelve included school-based intervention studies reported on an objective measure of daily energy expended. Supporting Information Figure S5 shows those that we were able to combine in a meta-analysis. Aburto et al. (39) randomized 27 Mexican schools to either a physical activity intervention or control. One cluster RCT evaluated educational materials for schools and families aiming to decrease screen time, increase fruit and vegetable consumption, and increasing physical activity (40). A further cluster RCT evaluated an interactive multimedia curriculum for promoting physical activity compared with an educational CD (41). A (nonrandomized) trial compared a pedometer intervention program in middle schoolers with control children (42). A cluster RCT compared a physical activity intervention for middle school girls with delayed intervention (43). One RCT assessed the effect of a 3-week pedometer intervention with set goals compared with wearing pedometers alone (44). Studies varied, and not all favored the intervention arm. Across studies, there was no statistically significant difference between intervention and control participants (SMD, -0.08; 95% CI: -0.65 to 0.49; six trials) (Supporting Information Figure S5).

Four additional RCTs reported on energy expended, but the effect size could not be calculated (Supporting Information Table S7).

One pre-post study reported a statistically significant effect of a school health approach for Appalachian youth (SMD, 0.65; 95% CI: 0.38-0.91; one pre-post study) (45). One pre-post study could not be combined with the previous study (Supporting Information Table S7).

We rated the quality of evidence as low because of the large variation in the studies that did not indicate that the effects are intervention specific.

Health education campaigns

Most identified systematic reviews ($n=211$) included education interventions. Sixty-two of these focused exclusively on education approaches such as public health campaigns in mass media or social media.

We identified 27 education studies meeting inclusion criteria. While the content of the intervention varied widely, participants in the studies were recruited through advertisements or mass mailings (i.e., not directly approached by their health care provider or recruited through school or work sites), and the studies did not involve any structural changes implemented in the physical environment.

Energy consumed. Of the included studies, 18 reported on energy consumed. This included an RCT evaluating the effects of an intensive diet and physical activity modification program, Complete Health Improvement Program (CHIP), compared with wait list (46). A further RCT investigated whether video games designed to promote behavior change enable children to learn healthier behaviors (47). One RCT explored the maintenance of weight loss in middle-aged women with overweight using an internet-based intervention (48). One RCT compared personalized dietary counseling via lay health advisors plus tailored print materials delivered via the mail in Latinas compared with targeted, mailed, “off-the-shelf” materials (49). An RCT studied the effect of diet and exercise in postmenopausal women compared with a control group (50). One of the identified RCTs addressed the efficacy of a 2-year obesity prevention program in African American girls compared with a control group (51). One RCT evaluated the effect of dietary counseling compared with information material only (52). A further RCT assessed the effect of a lifestyle intervention to prevent weight gain during menopause compared with no intervention (53). In one of the included RCTs, the intervention group participated in a 4-hour prevention program, whereas the control group received only an educational brochure (54). A family-based community-centered program of skills-building sessions was evaluated in another RCT (55). The pooled result showed a small effect for reduced energy

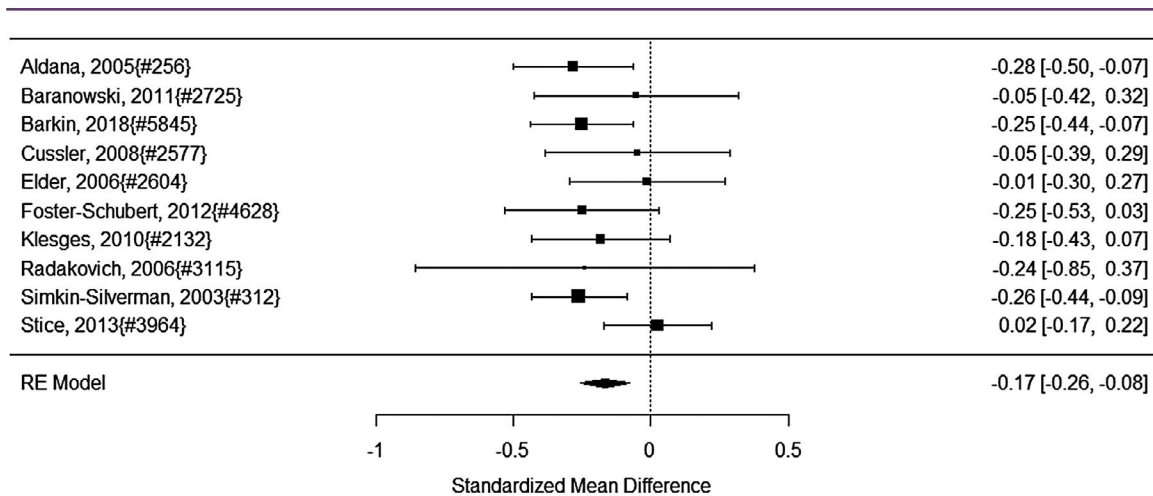


Figure 4 Estimated effects of health education campaigns on energy consumed.

consumed (SMD, -0.17 ; 95% CI: -0.26 to -0.08 ; 10 RCTs) (Figure 4). The I^2 statistic indicated negligible heterogeneity (18%). There was no evidence of publication bias (Begg $P=0.29$, Egger $P=0.52$). The graph included three studies that were exclusively in children (47,51,55). The effect was similar but not statistically significant in this subgroup (SMD, -0.20 ; 95% CI: -0.41 to 0.01 ; three RCTs). Other identified studies evaluated the comparative effectiveness of different obesity prevention interventions (Supporting Information Table S7).

Three included studies did not report on a concurrent comparator. A pre-post study evaluated a Web-based intervention to influence health behavior (56). A further pre-post study assessed energy consumed in the context of a weight management program using the food-exchange system (57). Although both pre-post studies reported positive effects, the estimates varied widely, and the pooled estimate was not statistically significant (SMD, -0.54 ; 95% CI: -3.76 to 2.69 ; two pre-post studies). One pre-post study could not be combined with the other studies because no measure of dispersion was reported (Supporting Information Table S7).

We determined that a moderate-quality body of evidence supports a small effect of reduced consumed energy (downgraded because of inconsistency).

Energy expended. In total, 12 studies evaluating educational interventions reported on daily energy expended. This included five of the RCTs already described that also reported on energy consumed and that compared with a passive control group (46,47,50,51,53). In addition, an RCT randomizing older adults to a pedometer and interactive website-based intervention compared with control contributed to this analysis (58). One RCT evaluated an automated intervention for multiple health behaviors using conversational agents that also reported on energy expended (59). Furthermore, one RCT evaluated a peer-guided intervention for mothers participating in the Special Supplemental Nutrition Program for Women, Infants, and Children (60). One RCT randomized older participants to volunteering in public school or a low-activity control group (61). An additional RCT investigated the impact of a brief intervention for working

mothers compared with waiting list control (62). The effects of the interventions varied widely, but the pooled effect was statistically significantly different from the control arm (SMD, 0.37 ; 95% CI: 0.07 to 0.67 ; 10 RCTs). There was substantial heterogeneity (I^2 83%) but no indication of publication bias (Begg $P=0.86$, Egger $P=0.70$). The two studies exclusively enrolling children did not find differences between groups (SMD, 0.06 ; 95% CI: -0.41 to 0.52 ; two RCTs) (47,51). Two comparative effectiveness studies and one RCT not adjusted for clustering are described in Supporting Information Table S6.

Two of the pre-post studies reported on energy expended (56,63). One evaluated the effect of a statewide campaign to increase activity levels (63). The other study evaluated a Web-based intervention to influence health behavior (56). Both studies reported a positive effect, and across studies, we estimated a small to medium effect on energy expended (SMD, 0.48 ; 95% CI: 0.16 - 0.79 ; two pre-post studies) (Figure 5). Heterogeneity was low (I^2 6%). Publication bias could not be assessed because of the small number of studies.

Education interventions may have a small effect on daily energy expended, but the quality of evidence was very low (the pooled effect in RCTs was not statistically significant, and the pre-post studies showed wide CIs).

Social-group approaches

The identified studies included 13 studies in which participants were recruited through existing social groups or community institutions, such as churches, Boy Scout groups, or established community programs.

Energy consumed. Of these social-group interventions to prevent obesity, two reported on energy consumed (64,65). One reported on a nutrition education program for women evaluated in an investigator-controlled nonrandomized trial (Expanded Food and Nutrition Education Program) (64), and the other evaluated a faith-based cardiovascular health promotion intervention for African American women in a cluster RCT (65). The studies reported conflicting results, and the large CI did not suggest that a mean effect estimate is appropriate (SMD, -0.05 ; 95% CI: -3.60 to 3.50 ; two trials).

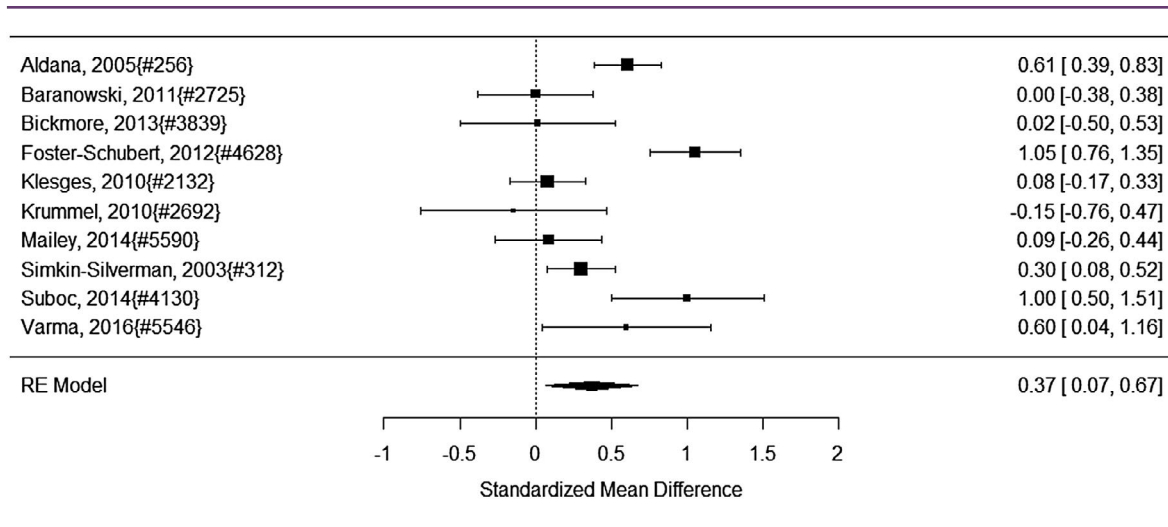


Figure 5 Estimated effects of health education campaigns on energy expended.

The quality of evidence was rated as very low because of the lack of consistency in results in the small number of studies that reported on the outcome dietary consumption.

Energy expended. Social-group interventions reported on energy expended (11 studies). Figure 6 shows studies that compared interventions with a concurrent control group. One study evaluated a faith-based, behavior-change, physical activity intervention for African Americans (66). One RCT compared the effect of a pedometer-based intervention for older adults with a wait list group (67). One study evaluated a YMCA after-school food and fitness program in a cluster RCT (68). Another cluster RCT evaluated a Boy Scout badge intervention to increase physical activity skills, self-efficacy, and goal setting compared with a control condition (69). One RCT evaluated a lifestyle behavior intervention for Hispanic women (70). A nonrandomized controlled trial focused on physical activity levels in low-income women (71). A cluster RCT used an intervention in churches to improve nutrition and physical activity (72). Another cluster RCT compared an intervention of culturally tailored dance and reducing screen time in low-income African American girls compared with information alone (73). Across studies, we found a medium effect of increased daily expenditure (SMD, 0.26; 95% CI: 0.07 to 0.44; eight trials). There was little evidence of heterogeneity (I^2 44%) and no indication of publication bias (Egger $P=0.37$, Begg $P=0.28$). Some of the studies targeted adults, and others targeted children (68,69,73). The effect estimate for the studies in children was lower, and the effect was not statistically significant (SMD, 0.17; 95% CI: -0.17 to 0.51; three RCTs) (Figure 6). A cluster RCT, a comparative effectiveness study, and a pre-post study could not be combined with the other studies (Supporting Information Table S7).

We determined the quality of evidence to be moderate that interventions increase physical activity using established social groups (downgraded because of inconsistency).

Other studies

Supporting Information Table S7 lists the individual studies not contributing to the effect estimates and shows studies categorized as “other” interventions because they did not describe how participants

were recruited or they paid university students to participate in an experiment. The references for these interventions are listed in Supporting Information Table S8.

Discussion

This systematic review included 99 studies across a diverse set of public health approaches to prevent obesity. Despite the major efforts these studies represent, we found limited evidence that interventions impacted energy intake and expenditure. Empirical evidence for changes in energy consumption or expenditure was sparse within intervention categories, and findings across studies often varied considerably. In many cases, we were unable to estimate effect sizes because studies provided insufficient details.

Health education campaigns made up the largest proportion of studies. The small pooled effect in reduced energy intake and the estimated effect of increasing energy expenditure suggest education programs reaching unselected participant samples can impact energy consumed and physical activity. Education programs are appealing because they can largely be delivered across large populations with relatively low cost. Yet the lack of tailoring to different groups of people with varying priorities and barriers to healthy lifestyles likely limits their ability to change behavior.

Despite literature searches in multiple sources, we did not identify food-labeling studies reporting on outcomes of interest. Existing food-labeling studies primarily focused on changes in food purchasing. While some promising evidence suggests that changing food labeling may improve food purchasing choices (74) without assessing changes in diet, it remains unknown whether and to what extent such interventions might reduce obesity. This lack of evidence is especially relevant given the US Food and Drug Administration Commissioner’s recent statement introducing federal food-labeling legislation (75).

Energy expenditure and intake outcomes were not reported across all intervention types. The intervention delivery approach drives which

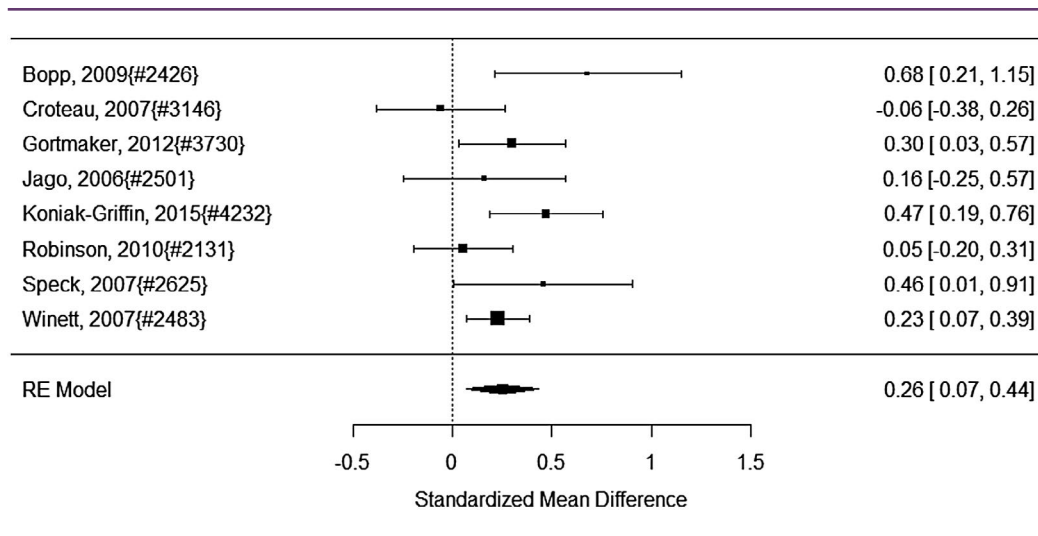


Figure 6 Estimated effects of social-group approaches on energy expended.

side of the energy balance equation can be targeted. For example, interventions that modified the physical environment and mode of transportation assessed impacts only on physical activity. However, the interventions that employed education and behavior-change support in broad social and situational contexts where people spend significant amounts of time were able to assess impacts on both energy intake and expenditure. These interventions included work site interventions, population health care interventions, school-based interventions, health education, and social-group interventions.

Population-based health care initiatives had the largest effect on reducing energy expenditure. The dietary interventions reached large audiences and were delivered either through clinics or online, but all were tailored to target behavior change for specific groups, such as low-income postpartum women (28) or urban adolescents (31).

Social-group interventions also showed promising effects on energy expenditure. This is consistent with conceptual behavior-change models (e.g., social-ecological model) (76,77) that address the importance of social factors and support for maintaining or increasing physical activity. Understanding how dietary choices are made in the context of personal and social influences that interact is critical to reducing obesity.

In this review, the interventions that included children were population health care, school-based, education, and social-group approaches. Despite possible plateaus in the prevalence of childhood obesity (78), rates are still high, and severe obesity is emerging as the fastest growing category of childhood obesity (79-81). Thus, effective interventions to improve energy balance for children early in life are still needed to prevent child and adult obesity. The only significant effect for children was reducing energy intake through school-based interventions. The school-based studies that examined effects on energy consumption were one of the few areas in which the quality of evidence was graded as moderate. School-based interventions may have more traction than other types of interventions to effect behavior change. Children must attend school, and if the intervention is part of a curriculum, then their participation is essentially guaranteed. Moreover, schools are settings where children

spend the majority of their day, consume about 30% of their calories from the school lunch alone (82), and have opportunities for physical activity. All these reasons point to schools as being potent settings to intervene on diet and physical activity. Moreover, parental involvement, beyond consent, in an obesity intervention has been suggested to improve its effectiveness (83,84). Parents have integral relationships with schools and may be more inclined to participate with their child in an intervention if it is embedded within a school with school leadership support. While we did not see a significant effect of the school-based interventions on physical activity, these studies had inconsistent findings and were graded as low. The variation could reflect the limited opportunities students have to be physically active at school (e.g., recess, physical education), so there is less time to increase child activity during their school day.

Even the statistically significant effect estimates were relatively small in magnitude. This may follow from the unique nature of the interventions. Modifying the built and social environments will change energy balance only distally. That is, many steps or choices happen between the environmental change and a person's decision to consume what type of and how much food and how physically active they will be. Small effects will be difficult to detect without adequate samples; therefore, many of the studies we reviewed may be underpowered. That is not to say that investigators did not present adequate power estimates. All RCTs included power calculations; however, BMI was often the primary outcome assessed. It may be that because BMI is a consequence of energy balance and further downstream from the intervention, proximal energy intake and expenditure should be considered the primary outcome in power and sample size estimates.

The studies we reviewed relied on recruited participants, so findings may be vulnerable to selection bias. Socially disadvantaged populations have historically been underrepresented in health research (85,86) which not only threatens generalizability but, often, the missing groups are also those with a high burden of disease. An assessment of selection bias in the reviewed studies is beyond the scope of this paper; however, the evidence should be considered in light of this limitation. We also recognize that our energy intake and expenditure reporting requirement

excluded other types of relevant population-level interventions (e.g., advertising restrictions) (87).

In addition to estimating the effects of included studies, our review identified a critical gap in the literature. Out of hundreds of potentially relevant studies, we had to exclude more than 90% because they did not meet our inclusion criteria, primarily because they did not measure or report energy consumption or expenditure. However, understanding effects on energy consumption and expenditure is needed if we are to understand obesity intervention effects and potential intervention targets.

A major challenge is to measure energy intake and expenditure accurately. In particular, population-based studies rely on self-reported food intake. Even 24-hour dietary recalls that are considered to be the best method to collect usual intakes are very limited by misreporting (88) and the limited nutrient databases relative to the massive number of items available for consumption (89). Thus, developing new technologies to collect the types and amounts of foods and beverages people eat in real time is sorely needed to significantly improve the accuracy with which we can measure diet. Moreover, we acknowledge that even measurement accuracy is not all that is needed to understand effects of environmental change on energy balance. We noted how the intervention target determined whether energy intake or expenditure was measured. Changes in energy balance and body weight cannot be predicted from a change in a single component of energy balance. People's physical activity and dietary behaviors are intertwined, and an intervention that targets either energy intake or expenditure could lead to compensation such that people change their behavior in the other energy balance component. Thus, studies to reduce obesity need affordable methods to objectively measure both physical activity and energy intake simultaneously across all types of studies accurately.

With technological advances, researchers may be able to better collect dietary and activity data in real time. Linking people in place and time by capturing high-quality space-time-behavior data (e.g., using global positioning systems) is a promising approach. For example, ecological momentary assessment is a technique to collect repeated samples of people's behaviors and experiences in real time and in their natural environment (90), and it can integrate psychosocial aspects with contextual experiences, such as who is with the subject and current feelings. Linking ecological momentary assessment with mobile dietary recording or accelerometry may facilitate collecting these critical data across all intervention settings.

New methods may also help assess multiple cross-sectoral and environmental efforts with small effects. For example, mental models approach is a multistage, mixed methods approach to understanding and influencing people's decision processes (91) and can provide a framework to conceptualize where, what, why, and with whom people purchase and consume food or choose an activity. By building a model of influences for a particular choice or set of choices, researchers can better understand the chain of events and decisions (e.g., diet, physical activity) in complex environments.

Conclusion

Understanding the impact of public health obesity interventions on energy balance is critical to reducing obesity. Despite current research on obesity prevention, very few studies provide relevant information

on energy intake and expenditure. Existing evidence with statistically significant effects to inform policies is limited. We found school-based approaches and health care initiatives reduced energy consumed, education reduced energy consumed and increased energy expended, and social-group approaches increased energy expenditure, but effects were small to moderate. We recommend future research address the divide between public health obesity interventions and energy balance to clarify how prevention and treatment efforts fail and succeed. **O**

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