

Systematic Review

Environmental Interventions to Reduce the Consumption of Sugar-Sweetened Beverages: Abridged Cochrane Systematic Review

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Keywords

Sugar-sweetened beverages · Interventions · Systematic review · Cochrane

Abstract

Background: Regular consumption of sugar-sweetened beverages (SSB) can increase the risk for obesity, type 2 diabetes, cardiovascular disease, and dental caries. Interventions that alter the physical or social environment in which individuals make beverage choices have been proposed to reduce the consumption of SSB. **Methods:** We included randomised controlled, non-randomised controlled, and interrupted time series studies on environmental interventions, with or without behavioural co-interventions, implemented in real-world settings, lasting at least 12 weeks, and including at least 40 individuals. Studies on the taxation of SSB were not included, as these are subject of a separate Cochrane review. We used standard Cochrane methods for data extraction, risk of bias assessment, and evidence grading and synthesis. Searches were updated to January 24, 2018. **Results:** We identified 14,488 unique records and assessed 1,030 full texts for eligibility. We included 58 studies comprising a total of 1,180,096 participants and a median length of follow-up of 10 months. We found moderate-certainty evidence for consistent associations with decreases in SSB consumption or sales for the following interventions: traffic light labelling, price increases on SSB, in-store promotion of healthier beverages in supermarkets, government food benefit programs with incentives for

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purchasing fruits and vegetables and restrictions on SSB purchases, multi-component community campaigns focused on SSB, and interventions improving the availability of low-calorie beverages in the home environment. For the remaining interventions we found low- to very-low-certainty evidence for associations showing varying degrees of consistency. **Conclusions:** With observed benefits outweighing observed harms, we suggest that environmental interventions to reduce the consumption of SSB be considered as part of a wider set of measures to improve population-level nutrition. Implementation should be accompanied by evaluations using appropriate methods. Future studies should examine population-level effects of interventions suitable for large-scale implementation, and interventions and settings not yet studied thoroughly.

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Introduction

Sugar-sweetened beverages (SSB) – defined as non-alcoholic, non-dairy beverages with added caloric sweeteners – have been linked to a number of adverse health outcomes. There is evidence for a causal role of SSB in the development of overweight and obesity from randomised controlled trials (RCTs) in children and youth and from systematic reviews of randomised controlled and observational studies in various age groups [1–4]. Moreover, systematic reviews of observational studies have found positive associations between SSB intake and type 2 diabetes [5], cardiovascular disease [6], and dental caries [7].

SSB consumption varies considerably by geographic location, gender, age, and socioeconomic status. Based on a systematic review and pooled analysis of dietary surveys, global mean adult daily SSB consumption was estimated at 137 mL (95% CI 88–211 mL) in 2010 [8]. Mean daily SSB consumption is higher in upper-middle-income countries (189 mL) and lower-middle-income countries (140 mL) than in high-income (121 mL) and low-income (83 mL) countries, with substantial variation between countries [8]. Among the populations with the highest intake, SSB constitute a substantial source of energy. In the US, mean SSB consumption in 2010 was estimated to account for 8 and 7% of total energy intake among youth and adults respectively [9]. In most high-income countries, SSB intake is higher among disadvantaged than among relatively more privileged population groups [10].

Public health and medical organisations have therefore called for efforts to decrease population-level SSB consumption. This includes environmental interventions, which target the physical and social environments in which individuals make food and beverage choices, as well as behavioural interventions, which target individuals and seek to alter their dietary preferences, knowledge, attitudes, motivations, skills, and abilities [11]. Systematic reviews that included RCTs and observational studies on behavioural interventions [12–14], and systematic reviews of observational studies on SSB taxes have concluded that these can be effective in reducing SSB intake [15]. Less is known on other types of environmental interventions. In this summary of a Cochrane systematic review [16], we therefore examine the effects of non-tax environmental interventions to reduce the consumption of SSB.

Methods

This is an abridged version of a Cochrane systematic review. The protocol [17] and Cochrane review [16] are available open access from the Cochrane Library, and provide a detailed description of methods and results. Ethical approval was not required for this research.

Inclusion Criteria

Online supplementary File 1, Table S1 (for all online suppl. material, see www.karger.com/doi/10.1159/000508843) provides an overview on inclusion criteria.

Study Type

We included the following study types, as recommended by the Cochrane Effective Practice and Organization of Care (EPOC) Group [18]: RCTs, non-randomised controlled trials (NRCTs), controlled before-after (CBA) studies, interrupted time series (ITS) studies, and repeated measures studies (RMS). For the classification of study designs, we used the algorithm provided by EPOC [18]. We included only study designs that satisfy the following criteria:

- For cluster-RCTs, NRCTs, and CBA studies: studies with at least 2 intervention and 2 control sites.
- For ITS studies and RMS: a clearly defined point in time when the intervention occurred and at least 3 data points before and 3 data points after the intervention.

We included non-randomised study designs in order to cover a broader set of study populations, intervention types, and intervention contexts.

Participants

Any participants, including adults, adolescents, and children, regardless of their weight and health status. We included studies that collected data on individual participants, and studies based on data not linked to individual participants, such as sales data.

Interventions

We included environmental interventions, defined as interventions that aim to alter the food and beverage environment in a way which can, in principle, be permanent. Interventions that alter the food and beverage environment temporarily with the aim of influencing individual preferences (e.g., one-off public media campaigns) were considered as behavioural interventions and were not included in this review.

We excluded the following:

- Studies on the taxation of SSB, as these are the subject of a separate Cochrane review [19]
- Studies conducted in laboratory or virtual settings, as the results may not be generalisable to real-world environments
- Studies with a follow-up period of <12 weeks, as the effects may not be sustained
- Very small studies with <20 individuals in each the intervention or control group, as the results may not be generalisable
- Studies in which participants are administered pre-defined amounts of SSB or alternatives to SSB, as these studies provide only limited evidence on the feasibility and effectiveness of public health interventions aimed at reducing SSB intake among free-living individuals
- Studies on interventions not focused on SSB and not reporting beverage-specific outcome measures, as it would be difficult to attribute effects to the intervention components of interest

We defined SSB as non-alcoholic, non-dairy beverages with added caloric sweeteners. Based on feedback from members of our review advisory group (listed in online suppl. File 1, Table S2), we also included studies targeting sugar-sweetened milk, but analysed these separately. Dietary guidelines generally recommend to choose unsweetened milk [20], but it remains controversial whether sugar-sweetened milk should be targeted in public health interventions or not [21]. It has been argued that limits on the consumption of sugar-sweetened milk could decrease overall milk intake, and thus overall dietary quality [21]. We

therefore considered interventions targeting sugar-sweetened milk separate from those targeting SSB and considered effects on total milk intake as potential adverse outcome [21].

100% fruit juice (i.e., fruit juice without added sugars) can have a sugar content similar to that of many SSB and may have adverse health effects when consumed excessively [22]. It can, however, also be a relevant source of essential nutrients, in particular for populations with limited access to fresh fruits and vegetables [22]. Based on feedback from our Review Advisory Group, we therefore decided not to consider interventions targeting 100% fruit juice in this review.

The comparison was no, minimal, or alternative intervention, such as behavioural intervention only.

Outcomes

We included studies reporting effects on direct or indirect measures of SSB and sugar-sweetened milk intake (including consumption, purchasing, and sales data), diet-related anthropometric measures and health outcomes, or any adverse outcome or unintended consequence.

Search Methods

We searched 11 general, specialist, and regional databases, including: MEDLINE, Embase, CENTRAL, Scopus, Google Scholar, Social Science Citation Index, eLINA, openGrey, SciELO Citation Index, and LILACS. We used Scopus to search reference lists and citations of existing reviews and included studies. We scanned websites of relevant organisations and contacted study authors and members of our review advisory group. To identify ongoing or completed, but unpublished studies, we searched the WHO International Clinical Trials Registry Platform (ICTRP) and ClinicalTrials.gov. No date or language restrictions were applied, and electronic searches were updated to January 24, 2018 (by P.P.). The full search strategy is provided in online supplementary File 2.

Study Selection

Two review authors independently screened titles and abstracts of all studies, removing those which were clearly not relevant. Subsequently, 2 review authors independently assessed full texts of all studies selected in step one for eligibility. Disagreement was resolved by discussion, and where necessary by consulting a third review author. We used EndNote and Zotero to collect and de-duplicate studies, the web application Rayyan for title and abstract screening, and Excel to document reasons for exclusion at full text screening stage. Screening was done by P.P., J.M.S., J.B., L.K.B., L.M.P., and S.P.

Data Extraction and Management

Two review authors (P.P., J.M.S., J.B., L.K.B., L.M.P., S.P., or C.H.) independently extracted study characteristics and study data with an electronic data extraction form (shown in online suppl. File 2). Inconsistencies were resolved by discussion, and where necessary by consulting a third review author. The final agreed data were entered into Review Manager 5.3 by P.P., and checked by J.M.S. We used the difference in means as main measure of effects. We extracted both adjusted and unadjusted results but used adjusted results for our evidence synthesis. In studies reporting several alternative measures for the same outcome, we used the outcome measure pre-specified as primary by the study in question, or alternatively the most conservative effect estimate reported. For studies reporting data on several time points, we used data for the last follow-up assessment conducted during the intervention phase. We extracted both data on the total number of participants recruited, enrolled or allocated, and on the number of participants included in analyses, and used the latter for our evidence synthesis.

In cases in which missing data on study characteristics or outcome measures precluded study inclusion or limited the use of a study at further stages of the review, we contacted the corresponding author. For registered but unpublished trials, we contacted the corresponding investigator to request relevant data.

Assessment of Risk of Bias

Risk of bias of included studies was independently assessed by 2 review authors (P.P., J.M.S., J.B., L.K.B., L.M.P., S.P., or C.H.) with the Cochrane risk of bias tool adapted by EPOC for non-randomised study designs [18]. Inconsistencies were resolved by discussion, and where necessary by consulting a third review author.

Data Synthesis

We classified interventions with the NOURISHING framework into 7 broad intervention areas [11] and created in an ad hoc manner an eighth intervention area for home-based interventions. Based on feedback from our review advisory group, we further subdivided these 8 intervention areas in an ad hoc manner into 24 intervention types in order to improve the review's usefulness for decision-makers. The resulting typology of interventions is shown in online supplementary File 1, Table S3. We examined results for each of the 24 intervention types separately. Results were synthesised narratively and with tables. We conducted meta-analyses where methods and populations, interventions, comparisons, and outcomes were sufficiently homogenous.

Assessment of the Certainty of Evidence

We assessed our confidence in the certainty of evidence with the GRADE framework as very low, low, moderate, or high, using GRADE guidance [23]. In GRADE, there are 5 factors that can lead to a downgrading of the level of evidence (risk of bias, indirectness, inconsistency, imprecision, and publication bias) and 3 factors that can increase the level of evidence (magnitude of effect size, direction of plausible confounding, and dose-response gradient) [23]. In GRADE, the term “certainty of evidence” refers to our confidence that effects lie within a particular range, or on one side of a particular threshold [23]. For population-level public health interventions, any difference from the null may be potentially relevant, in particular for low-cost or cost-neutral interventions. We therefore used the difference from the null as threshold for the potential public health relevance of reported effects. The certainty of evidence therefore refers to our confidence that effects are different from the null. We did, however, document any cases in which reported effect sizes were small, and may arguably be of limited practical relevance. This was the case for 2 studies [24, 25].

Public Involvement

We formed a review advisory group with evidence users, including representatives of government agencies, international organisations, civil society, and academia, which were consulted at various stages of the review process. We have developed a dissemination plan involving our review advisory group and a variety of further stakeholders.

Results

Results of the Search

We identified 14,488 unique records and assessed 1,030 full texts for eligibility. Fifty-eight studies met our inclusion criteria, including 22 RCTs, 3 NRCTs, 14 CBA studies, and 19 ITS studies. Details on the search and screening process are shown in the PRISMA flow chart

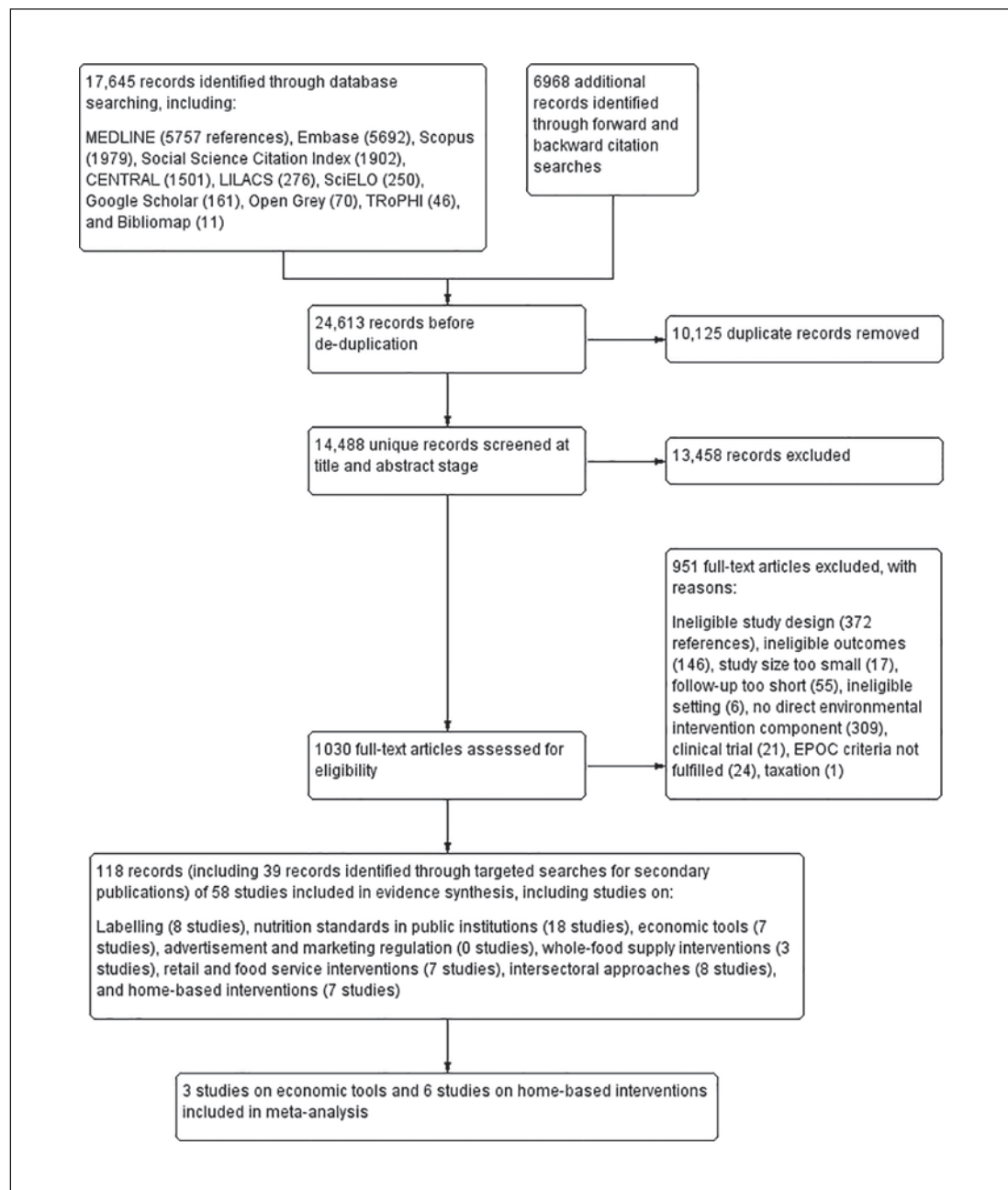


Fig. 1. PRISMA flow chart.

in Figure 1. Thirty-six studies collected data on individual participants, and 22 studies were based on sales data not linked to individual participants. The studies reporting participant numbers included a total of 1,180,096 participants (range 93–1,065,562, median 1,032). The combined length of intervention and follow-up ranged from 3 months to 6 years, with a median length of 10 months. Most studies were conducted in North America ($n = 40$ studies, 69% of included studies), Western Europe ($n = 8$, 14%), and high-income Australasia ($n = 6$, 10%). Tables 1 and 2 provide an overview of methodological aspects and on participants, context, and implementation of included studies, respectively.

Table 1. Characteristics of included studies – methods

Study design	Studies, <i>n</i> (% of included studies)
RCTs	22 (38)
ITS studies	19 (33)
CBA/NRCTs	17 (29)
Data collection methods (multiple counts)	
Self-reported SSB intake	24 (41)
Electronic sales data	22 (38)
Production and sales data provided by market research firms	8 (14)
Observations by trained observers	3 (5)
Grocery and restaurant receipts collected from participants	2 (3)
Administrative data bases on beverage deliveries to schools	1 (2)
Type of outcome data	
Data linked to individual participants	36 (62)
Transaction data, not linked to individual participants	22 (38)

RCT, randomised controlled trial; ITS, interrupted time series study; CBA, controlled before-after study; NRCT, non-randomised controlled trial.

Table 2. Characteristics of included studies – participants, context, and implementation

Age group of participants	Studies, <i>n</i> (% of included studies)
Children	12 (21)
Children and teenagers	8 (14)
Teenagers	7 (12)
Adults	9 (16)
Not specified/participants of all ages	22 (38)
Setting	
Schools	20 (34)
Retailing	12 (21)
Homes	7 (12)
Food service	6 (10)
Other	13 (22)
Country	
US	38 (66)
Australia	4 (7)
The Netherlands	3 (5)
Canada	2 (3)
UK	2 (3)
Other	9 (16)
Mode of implementation	
Pilot trial by researchers	29 (50)
Mandatory government regulation	16 (28)
Voluntary industry action	9 (16)
Government pilot project	4 (7)

Risk of Bias and Certainty of Evidence

We judged most studies to be of high or unclear risk of bias in at least one domain (see online suppl. File 1, Fig. S1, 2). For a number of intervention types and outcomes most or all included studies reported effect estimates with 95% CIs that were large and included both

Table 3. Effects on direct and indirect measures of SSB consumption reported by included studies

Direction of effects	Certainty of evidence	Intervention	Supporting studies	Follow-up, months	Number of clusters, sites and/or participants	Country	
Decreased SSB consumption	⊕⊕⊕⊕ Moderate	Traffic light labelling	2 ITS [26, 27] ^a	12	42 points of sale in 2 hospitals in 2 cities	Australia, US	
		Price increases on SSB	3 ITS [28–30] [†]	4–12	1 store, 7 leisure centres and 37 restaurants in 29 cities	Australia, UK	
	⊕⊕⊕⊕ Low	In-store promotion of healthier beverages in supermarkets	1 cluster-RCT [31] ^e		6	8 supermarkets from 2 chains	US
		Food benefit programs with incentives for purchasing fruits and vegetables and restrictions on SSB purchases	3 RCTs [32–34] ^b		3–12	2,274 adults and 18,207 children	US
		Community campaigns focused on SSB	1 controlled ITS [35] ^a		36	32 supermarkets from 6 chains in 2 countries	US
		Home-based interventions improving the availability of healthier beverages in the home environment	6 RCTs [3, 4, 36–39] ^b		4–12	1,130 children, teenagers and adults	US, Mexico, Chile
		Nutritional rating score shelf labelling	1 ITS, [41] 1 CBA [40]		7–11	442 stores from 4 chains in 2 countries	US, Canada
		Reduced availability of SSB in schools	5 CBA [42–45]		6–24	18,238 students in 240 schools	US
		Healthier default beverages in children's menus in chain restaurants	1 ITS study [46] ^{a, b}		72	145 restaurants in 1 theme park	US
		Improved access to drinking water at school	1 CBA [47], 3 NRCTs [24, 48, 49] ^{b, d, e}		3–13	11,253 students in 62 schools	US, Germany, Netherlands
Inconsistent effects	⊕⊕⊕⊕ Very low	Fruit provision at school	1 RCT [71], 1 CBA [50] ^{f, g, h}	9–72	3,494 students in 47 schools	Brazil, Norway	
		Urban planning restrictions on new fast-food restaurants	1 CBA [51] ^b	36–48	11,821 inhabitants of 1 city and 1 county	US	
	⊕⊕⊕⊕ Low	Restrictions to the number of stores selling SSB in remote communities	1 ITS [52] ^{b, e}		8	3 stores in 1 remote community	Canada
		Provision of active video gaming equipment to teenagers	1 RCT [72] ^{e, i}		10	262 teenagers	Netherlands
		Price discounts on low-calorie beverages implemented through supermarket loyalty cards	3 RCTs [55–57] ^{b, e}		3–6	1,750 customers of 3 supermarket chains	Australia, New Zealand, US
		Food benefit programs without restrictions on SSB	1 RCT [32], 1 CBA [65] ^{b, e}		3–8	25,150 children and 2,844 adults	US
		Menu board calorie labelling in chain restaurants and cafés	1 controlled ITS [25], 2 CBA [53, 54] ^{b, c}		4–12	353 stores from 4 chains in 6 cities	US
		Industry self-regulation and voluntary industry initiatives to improve the nutritional quality of the whole food supply	2 controlled ITS [58, 60], 1 CBA [59] ^b		36–48	61,126 households and 17 companies	US
		Healthier vending machines in workplaces and schools	2 NRCTs [61, 62] ^{b, d, h}		18–24	6 schools and 4 worksites	US
		Trade and investment liberalization in low- and middle income countries	2 controlled ITS [63, 64] ^b		48	4 countries	Bolivia, Peru, Vietnam, Philippines
Increased SSB consumption	⊕⊕⊕⊕ Low	Price discounts on low-calorie beverages in community stores	1 cluster-RCT [68] ^{b, e}	6	8,515 inhabitants of 20 remote indigenous communities	Australia	

CBA, controlled before-after study; ITS, interrupted time series study; NRCT, non-randomised controlled trial; RCT, randomised controlled trial; SSB, sugar-sweetened beverages. Down- and upgrading decisions informing the assessment of the certainty of evidence with GRADE: ^a Upgraded for magnitude of effect. ^b Downgraded for risk of bias. ^c Downgraded for indirectness. ^d van de Gaar et al. [49] and French et al. [62] were cluster-RCTs with four units, of which 2 were allocated by the flip of a coin to the intervention group. Given the small number of randomised units, randomization may not have been sufficient to attain baseline comparability of the intervention and control group. We therefore included the 2 studies as NRCTs in our evidence synthesis. ^e Downgraded for imprecision. ^f Downgraded by one level for risk of bias and by one level for imprecision (da Costa et al. [71]). ^g Downgraded by one level for risk of bias (Øverby et al. [50]). ^h Downgraded for publication bias. ⁱ Upgraded by one level for dose-response gradient and magnitude of effect. [†] Downgraded by 2 levels for risk of bias.

Table 4. Effects on body weight outcomes reported by included studies

Direction of effects	Certainty of evidence	Intervention	Supporting studies	Follow-up, months	Number of clusters, sites and/or participants	Country
Decrease in body weight	⊕⊕⊕⊕ High	Improved access to low-calorie beverages in the home environment, compared to no intervention	2 RCTs [3, 4]	6–12	320 teenagers	US
	⊕⊕⊕⊖ Low	Improved access to low-calorie beverages in the home environment compared to general weight loss counselling	2 RCTs [38, 39] ^{a, b}	6–9	558 adults	US
	⊕⊕⊖⊖ Very low	Improved access to drinking water in schools	1 NRCT [48], 1 CBA [66], and 1 cluster RCT [49] ^{a, b}	10–60	1,069,521 students at 1,231 schools	US, Germany, Netherlands

CBA, controlled before-after study; NRCT, non-randomised controlled trial; RCT, randomised controlled trial. Down- und upgrading decisions informing the assessment of the certainty of evidence with GRADE: ^a Downgraded for risk of bias. ^b Downgraded for imprecision.

the possibility of relevant benefit and null effects or harm. We therefore downgraded the level of evidence for most interventions and most outcomes for risk of bias, imprecision, or both [23]. For 3 intervention types (school fruit programs, healthier vending machines, and provision of active video gaming equipment), we downgraded the certainty of evidence for suspected publication bias, as we identified studies on these intervention types that had assessed but did not fully report effects on SSB intake. In one case (menu board calorie labelling), we downgraded the certainty of evidence for indirectness, as all studies providing data on this intervention type reported only an indirect measure for SSB intake, namely calories from beverages per transaction. In 4 cases (traffic light labelling, price increases on SSB, healthier default beverages in children's menus in chain restaurants, and community campaigns focused on SSB), we judged the observed effect size to be large, and unlikely to have arisen by chance or due to bias, and upgraded the certainty of evidence for this reason. Our confidence in the certainty of most effect estimates showing a non-null effect is therefore moderate, low, or very low. Details on the assessment of the certainty of evidence for each outcome and each intervention type are provided in the footnotes to Tables 3–5 and in the full Cochrane review [16].

Effects on SSB Consumption

Heterogeneity in methods as well as in population, intervention, comparison, and outcomes precluded meta-analysis for most outcomes and intervention types. The direction of reported effects on SSB consumption and body weight, as well as key aspects of the supporting evidence are shown in Tables 3 and 4, respectively. Full quantitative results for all outcomes and all intervention types are shown in the Cochrane version of this review.

For 6 intervention types, we found moderate-certainty evidence for consistent associations with decreases in direct or indirect measures of SSB consumption: traffic light labelling [26, 27]; price increases on SSB [28–30]; in-store promotion of healthier beverages in supermarkets [31]; food benefit programs with incentives for purchasing fruits and vegetables and restrictions on SSB purchases [32–34]; community campaigns focused on SSB [35]; and interventions improving the availability of healthier beverages in the home environment [3, 4, 36–39].

We found low-certainty evidence for consistent associations with decreases in SSB consumption for: nutritional rating score shelf labelling [40, 41]; limits on the availability of SSB in schools [42–45]; and healthier default beverages in children's menus in chain restaurants [46].

Table 5. Effects on potential adverse outcomes reported by studies on interventions targeting SSB

Type of adverse outcome	Intervention type	Direction of effects	Certainty of evidence	Supporting studies	Follow-up, months	Number of participants, clusters or sites	Country
Revenue	Traffic light labelling	Inconsistent effects	⊕⊕⊕⊕ Low	2 ITS studies [26, 27]	12	42 points of sale in 2 hospitals in 2 cities	Australia, US
	Nutritional rating score shelf labels	Inconsistent effects	⊕⊕⊕⊕ Low	1 ITS [41] and 1 CBA study [40]	7–11	442 stores from 4 chains in 2 countries	US, Canada
	Menu board calorie labelling	Increase	⊕⊕⊕⊕ Very low ^{a,b}	1 controlled ITS study [25]	11	316 stores from 1 chain in 2 cities	US
	Healthier vending machines in workplaces and schools	Decrease	⊕⊕⊕⊕ Low ^c	1 cluster-RCT [67]	5	1 worksite	US
	Price increases on SSB	Decrease	⊕⊕⊕⊕ Low	2 ITS studies [29, 30]	4–12	1 convenience store and 7 leisure centres	Australia, UK
Compensatory behaviours (energy-balance and nutrition-related behaviours other than SSB intake)	Nutritional rating score shelf-labels in supermarkets	Improved overall dietary quality	⊕⊕⊕⊕ Low	1 ITS [41] and 1 CBA study [40]	7–11	442 stores from 4 chains in 2 countries	US, Canada
	Menu board calorie labelling	Inconsistent effects	⊕⊕⊕⊕ Very low ^a	1 controlled ITS [25] and 2 CBA studies [53, 54]	4–12	353 stores from 4 chains in 6 cities and counties	US
	Financial incentives to purchase low-calorie beverages implemented through supermarket loyalty cards	Increased purchases of less healthy products	⊕⊕⊕⊕ Low ^{a,b}	1 RCT [56]	6	1,028 customers of 1 supermarket chain	New Zealand
	Price discounts on low-calorie beverages in community stores	Increased total energy content of grocery purchases	⊕⊕⊕⊕ Low ^{a,b}	1 cluster-RCT [68]	6	8,515 inhabitants of 20 remote indigenous communities	Australia
SSB purchases outside school	Reduced availability of SSB in schools	Inconsistent effects	⊕⊕⊕⊕ Very low ^b	2 CBA studies [45, 69] and 1 controlled ITS [25]	6–36	11,331 households in 51 school districts	US
Total milk intake	Improved access to drinking water in schools	Decrease	⊕⊕⊕⊕ Very low ^a	1 CBA study [66] and 1 NRCT [47]	10–60	1,066,947 students in 1,246 schools	US
Alcoholic beverage intake	Government food benefit programs with incentives and restrictions	Increase	⊕⊕⊕⊕ Low ^c	1 RCT [34]	9–11	2,009 adults	US
Body dissatisfaction and dieting behaviour	Reduced availability of SSB in schools	No effects (data not shown)	⊕⊕⊕⊕ Very low ^{a,b}	1 CBA study [45]	12	495 students in 6 schools	US

CBA, controlled before-after study; ITS, interrupted time series study; NRCT, non-randomised controlled trial; RCT, randomised controlled trial; SSB, sugar-sweetened beverages. Down- and upgrading decisions informing the assessment of the certainty of evidence with GRADE: ^a Downgraded for risk of bias. ^b Downgraded for imprecision. ^c Downgraded by two levels for risk of bias.

We found very low-certainty evidence for associations with decreases in SSB consumption for: improved access to drinking water at school [24, 47–49]; fruit provision at school [50]; urban planning restrictions on new fast-food restaurants [51]; and restrictions on the number of stores selling SSB in remote communities [52].

For the following intervention types, we found inconsistent associations with SSB consumption: menu board calorie labelling in chain restaurants and cafés [25, 53, 54]; price discounts on low-calorie beverages implemented through supermarket loyalty cards [55–57]; industry self-regulation and voluntary industry initiatives to improve the nutritional quality of the whole food supply [58–60]; healthier vending machines in workplaces and schools [61, 62]; trade and investment liberalisation in low- and middle-income countries [63, 64]; and food benefit programs without restrictions on SSB [32, 65].

Moreover, we found high-certainty evidence that interventions improving the availability of low-calorie beverages in the home environment of adolescents with a high baseline consumption of SSB are associated with a smaller gain in body weight compared to no intervention [3, 4]. We found low-certainty evidence that such interventions are associated with reduced body weight among adults when compared with general weight loss counselling [38, 39]. Moreover, we found very low-certainty evidence that improved access to drinking water at school may be associated with reduced body weight [48, 49, 66].

We conducted a meta-analysis for 3 studies reporting on price increases of SSB [28–30]. Our pooled effect estimate is that SSB sales decreased by –19% (95% CI –33 to –6) at 4–12 months, with relevant subgroup differences according to the magnitude of the price increase (see online suppl. File 1, Fig. S3). Moreover, we conducted meta-analyses for 5 studies reporting effects on SSB consumption of improved access to low-calorie beverages in the home environment of individuals with a high baseline consumption of SSB [3, 4, 36–38]. Across these studies, SSB consumption decreased by –413 mL/day (95% CI –684 to –143) at 4–12 months (see online suppl. File 1, Fig. S4). Here, however, the graphical inspection of the forest plot and the I^2 statistic indicate substantial statistical heterogeneity, which may be explained by differences in population, intervention delivery, and context.

Adverse Outcomes and Unintended Consequences

Table 5 presents evidence on potential adverse outcomes and unintended consequences reported by included studies. These include effects on revenue [25–27, 29, 30, 40, 41, 67], various types of compensatory behaviour (defined as energy balance and nutrition-related behaviours other than SSB consumption, which may be directly or indirectly affected by the intervention) [25, 40, 41, 53, 54, 56, 68], as well as SSB purchases outside school when availability of SSB in schools is reduced [25, 45, 69]. We included effect estimates for these outcomes regardless of the reported direction of effect. Reported effects varied considerably. For example, 5 studies on labelling examined effects on total revenue, and one study each reported statistically significant positive [41] and negative [26] effects, while 3 studies reported effects not reaching statistical significance at the 5% level (2 positive [25, 27], and one negative effects [40]). Similarly, 3 studies examined effects on SSB purchases and consumption outside school when access to SSB at school is limited, and one study found a statistically significant increase for high-school students but decreases for middle and elementary school children [70], while 2 other studies examining middle schools [45] and a variety of different school types [69], respectively, found decreases that did not reach statistical significance at the 5% level.

Effects by Indicators of Social Disadvantage

Among the studies included in this review, 13 focused on socially disadvantaged participants [31–33, 48, 49, 51, 57, 65, 68, 73–75], and 9 report subgroup analyses by indicators of social disadvantage [3, 4, 25, 48–50, 53, 55, 56]. We present details on these in the full

Cochrane review [16]. In short, we found no clear pattern of differences in effectiveness by social disadvantage, but some indication that interventions can be effective in groups exposed to varying degrees and forms of social disadvantage.

Effects on Sugar-Sweetened Milk Consumption

We analysed results for interventions targeting sugar-sweetened milk separately. We found low- [74, 76] to moderate-certainty [77] evidence that small prizes for the selection of healthier beverages in elementary school cafeterias are associated with decreased consumption of sugar-sweetened milk, and low-certainty evidence that this is the case for emoticon labelling [73]. We found very-low-certainty evidence that improved access to drinking water in schools is associated with decreased intake of sugar-sweetened milk [66] and that improved placement of plain milk in school cafeterias is not associated with sugar-sweetened milk consumption [75]. Three studies on sugar-sweetened milk examined total milk intake [73, 74, 76], and reported effects varied in direction, size, and statistical significance.

Ongoing Studies

We conducted trial register searches to identify ongoing studies and found 10 studies which we judged likely to meet our eligibility criteria upon completion. This includes 4 studies on improved availability of drinking water in schools [78–81], 2 studies on improved availability of low-calorie beverages in the home environment [82, 83], and one study each on reduced availability of SSB and improved availability of drinking water in schools [84], reduced availability of SSB in workplaces [85], price increases on SSB [86], and the removal of SSB from supermarket checkout coolers [87]. Trial register searches may, however, provide only an incomplete picture of ongoing research in the field, given that only a small share of all completed studies included in this review reported registration. We contacted authors of all ongoing studies, but preliminary outcome data was not available for any of them. We therefore did not include these in our analysis.

Discussion

Principal Findings

The evidence included in this review shows that effective, scalable interventions addressing SSB consumption on a population level exist. With the observed benefits outweighing the observed harms, we suggest that those interventions showing consistent associations with reduced SSB consumption may be considered as part of a wider set of measures to improve population-level nutrition and associated health outcomes. Based on the findings of this review, this applies to the following approaches: interpretative nutrition labelling, including traffic light [26, 27] and nutritional rating score labelling [40, 41]; interventions limiting the availability of SSB in schools [42–45]; price increases on SSB [28–30, 42–45]; healthier default beverages in children's menus in chain restaurants [46]; in-store promotion of healthier beverages in supermarkets [31]; government food benefit programs with incentives to purchase fruits and vegetables and restrictions on purchasing SSB [32–34]; multi-component community campaigns focused on SSB [35]; and interventions improving access to low-calorie beverages in the home environment of participants with overweight and obesity and a high baseline consumption of SSB [3, 4, 36–39]. Further approaches to reduce the consumption of SSB exist, and may be effective, but the evidence in this review does not allow for clear conclusions regarding their effects. Behavioural interventions and taxation of SSB were not examined in this review.

Certainty of Evidence, Applicability, and Interpretation of Results

Based on our GRADE ratings, the certainty of evidence is low to moderate for most interventions and in relation to most outcomes. This means that future studies may find effects which may be substantially different in size and possibly direction from those reported in this review. When examining the existing evidence, decision makers should, however, consider that in public health, the effects of population-level interventions can rarely be established conclusively by conducting trials in controlled research settings [88]. Generating meaningful evidence on such interventions generally requires that policy makers and practitioners take action based on limited and imperfect evidence and implement interventions while ensuring that these are evaluated with appropriate methods, and reviewed, modified, or discontinued once stronger evidence on population-level effects emerges [88].

The studies included in this review cover a broad range of settings, including schools, supermarkets, restaurants and hospitals, among others. Twenty-three of the included studies were implemented on the level of political jurisdictions such as states or municipalities. We included only studies conducted in real world settings (excluding studies conducted in research laboratories and virtual environments) lasting at least 3 months. This strengthens our confidence that, overall, results are applicable to a variety of real world settings, and are scalable to a population level. For a number of intervention types, however, the evidence in this review is limited to specific settings, modes of delivery, or populations. Both studies on traffic light labelling, for example, were implemented in hospitals and included a number of co-interventions, such as awareness-raising campaigns [26, 27]. Only 4 studies were conducted in low- and middle-income countries [38, 63, 64, 71], and 38 of the 58 studies included in the review were conducted in the USA. The heterogeneity in effects observed for most interventions and outcomes may be partly due to differences in methods, population, intervention, comparison, and outcome measures, but may also be a sign of the context dependency typical of public health interventions. Implementation of interventions in contexts different from those in which they have been examined so far may therefore require adaptation and may produce effects different from those reported in this review. This also applies to those interventions for which this review found inconsistent effects on SSB intake, including, for example, menu board calorie labelling [25, 53, 54] and voluntary industry initiatives [58–60]. These may still constitute worthwhile approaches when adapted to a given context, and future studies may find them to be effective. Importantly, the evidence in this review does not allow to rule out relevant effects for any of the included intervention types. The absence of evidence for effects of some interventions should not be interpreted as evidence for the absence of effects.

Comparison with Other Studies

In a targeted search for existing systematic reviews on SSB interventions conducted on May 25, 2018, we identified 5 systematic reviews that included environmental interventions to reduce the consumption of SSB other than taxation, including 4 that are focused on children and adolescents [14, 89–91], and one which includes interventions targeting all age groups [13]. There is substantial variation in the focus, the search strategies, the eligibility criteria and various other methodological aspects used by the 5 existing systematic reviews and our review. Accordingly, the overlap among the studies included in these reviews is small: only 11 of the 58 studies included in our review are also included in one of the existing systematic reviews. Overall, the results of the 5 existing systematic reviews indicate that environmental interventions can contribute to reductions in SSB intake and are thus in line with the findings of our review.

Implications for Research and Practice

A broad range of factors interact to influence SSB consumption, including accessibility, availability, and price of SSB as well as population attitude, awareness, and social norms

related to the consumption of SSB and other sugary products, and SSB are consumed on a variety of occasions and locations [92]. It is therefore unlikely that any single intervention taken alone can effectively lower population-level SSB consumption to recommended levels [88]. It is encouraging that, as shown in this review, a broad range of interventions, implemented on a variety of levels by a variety of actors, can affect SSB consumption. Combining different approaches, and targeting a variety of contextual factors, settings, and population groups is likely to be necessary for bringing about the intended more substantial behavioural and health impacts [88].

Most of the interventions examined in this review are suitable for large-scale implementation and are likely to show the greatest population-level effect when implemented on this level. This, however, requires public and political support. The potential effectiveness of interventions in relation to their intended outcomes is only one of many factors influencing the likelihood of implementation. Adverse outcomes, in particular, feature prominently in the public and political debates around SSB interventions. It is therefore of relevance that we did not find consistent evidence for negative effects on outcomes such as stakeholder revenue or compensatory behaviours. Moreover, a sense of political dynamics, effective advocacy, and broad coalitions may help to achieve policy-level implementation, as described by Schwartz et al. [35], a study on a community campaign focused on SSB. While policy-level implementation may be desirable in most cases, implementation within specific settings, including hospitals [26, 27], may in many cases be a worthwhile and politically more viable option in the short-run. Moreover, when setting-level implementation is accompanied by evaluations using appropriate methods, it can support policy-level implementation by generating evidence, public visibility, and political momentum.

Conducting methodologically rigorous evaluations of population-level public health interventions poses unique challenges, and some of the studies in this review provide examples of how these can be addressed. Given that the implementation of such interventions often falls outside the capacity and authority of researchers, close and continuous cooperation with relevant stakeholders, such as public officials [30, 47, 66], civil society organisations [35], and private businesses [25, 28, 29, 31, 40, 41] is often required. Randomisation may be feasible in some cases [68]. Where this is not the case, relatively more sophisticated non-randomised study designs, such as interrupted time series studies [25, 26, 28–30, 35, 52, 70] and designs with synthetic control groups [44] may be used. Data limitations may be addressed by making optimal use of existing data sources, including routinely collected electronic sales data [25, 26, 28–31, 40, 41, 52] and sales and purchasing data provided by commercial market research firms [35, 58–60, 63, 64, 69, 70]. Effects of public health interventions may vary by socio-economic status, gender, ethnicity, and other dimensions of social (dis-)advantage, and future studies should pay tribute to such differential effects. Pre-registration is still uncommon in the field – none of the 38 non-randomised studies in our review reported registration – but is desirable for all study types. Most study registers, including clinicaltrials.gov, allow for the registration of observational studies, including studies conducted retrospectively with routinely collected data. When pre-registration is not considered feasible, publication of protocols [4, 33, 68] and declarations on protocol fidelity [28, 33] may help to alleviate concerns regarding reporting bias.

Limitations of This Review

This review has a number of limitations. We did not include studies on taxation of SSB and on behavioural (educational) interventions, as these are covered by existing or ongoing reviews [12–15, 19]. Moreover, we did not find any studies meeting our inclusion criteria on a number of approaches proposed for reducing the consumption of SSB or its effects on health, including:

- Advertisement and marketing regulations [93]
- Portion and package size reductions [94]
- Warning labels [95]
- National strategies to improve the quality of the whole food supply [96]
- Subsidies for and regulation of the production of sugar and other caloric sweeteners [97]
- Improved access to healthier beverages in small neighbourhood shops [98]

While studies have been conducted on these approaches, these did not meet our inclusion criteria with regard to follow-up [94, 95], outcomes [93, 96], or study design [97, 98].

Moreover, we conducted searches in English only, and note that 47 of the 58 included studies were conducted in Anglophone countries. We may have missed eligible studies published in languages other than English. We made a number of changes to the review's methodology after we had published the protocol and provide details on and the rationale for these changes in the full review published in the Cochrane Library [16]. We used reporting on primary outcomes as one eligibility criterion for studies, which limits our ability to ascertain the extent of reporting bias. We included studies reporting indirect measures of SSB consumption, including measures that are not specific to SSB, such as beverage calories per transaction [25, 53, 54] and energy density of beverages sold [56]. For a number of intervention types, the number of supporting studies was small and limited to specific settings and modes of implementation. We included studies on environmental interventions with behavioural co-interventions, which are likely to have influenced the observed effects. The classification of interventions as environmental or behavioural was in some cases ambiguous and required judgement by the review authors. We provide further details on these cases in the full review published in the Cochrane Library [16]. Our choice of 12 weeks as minimum length of follow-up required for inclusion may be considered arbitrary, and still represents a relatively short-term follow-up period. We used the Cochrane risk of bias tool adapted for non-randomised studies to assess risk of bias [18]. Using a more sophisticated tool, such as ROBINS-I, may have allowed us to better account for the relative strengths and weaknesses of different non-randomised study designs, both in the risk of bias assessment of individual studies and in the assessment of the certainty of evidence with GRADE.

Conclusions

Environmental interventions can help reduce population-level SSB consumption and should be considered as part of wider strategies to improve population-level nutrition. Their implementation should be accompanied by evaluations using appropriate study methods to strengthen the existing evidence base. There is a particular need for studies on population-level effects of interventions suitable for large-scale implementation, and on interventions, settings, and countries not yet examined thoroughly by existing studies.

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Statement of Ethics

Ethical approval was not required for this research.

Conflict of Interest Statement

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: J.M.S., J.B., L.K.B., L.M.P., S.P., and E.A.R. have received support from LMU Munich for the submitted work; J.M.S. has received support from the Bavarian Office for Health and Food Safety for the submitted work; P.P., C.H., and H.H. have received support from Technical University Munich for the submitted work; C.H. is a member of the scientific advisory board of 4sigma GmbH, a consultancy working primarily for health insurance companies; C.H. has been involved in the preparation of a systematic review on Associations between single nucleotide polymorphisms and macronutrient intake (PROSPERO: CRD42015025738), partly funded by an institutional grant from the consumer products company Amway GmbH; H.H. has received honoraria for membership on scientific advisory boards of Weight Watchers, NovoNordisk and Boehringer Ingelheim, and honoraria for membership on scientific advisory boards of Nestle and Danone, providing advice on recommendations regarding the nutritional content of breakfast meals and dairy products; H.H.'s institution has received grants from Riemser Pharma, Amway GmbH and Certmedica, a producer of slimming products; no other relationships or activities that could appear to have influenced the submitted work.

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Author Contributions

P.P. drafted the protocol with support from J.M.S., J.B., L.K.B., L.M.P., S.P., C.H., H.H., and E.A.R. P.P. developed the search strategy and conducted the searches. P.P., J.M.S., J.B., L.K.B., L.M.P., and S.P. selected studies, extracted data, and assessed the risk of bias of included studies. P.P. entered data into RevMan, conducted the analyses, graded the evidence, and drafted the manuscript. J.M.S. double-checked data entry, data analysis, and evidence grading. E.A.R. provided methodological support on all stages of the review process. P.P. is the guarantor of this manuscript. All authors had full access to all of the data (including statistical reports and tables) in the study and can take responsibility for the integrity of the data and the accuracy of the data analysis. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

Data Sharing

Full datasets can be obtained from the corresponding author at pphilipsborn@ibe.med.uni-muenchen.de.

Transparency

The lead author affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned and registered have been explained. A detailed description of all differences between the review and the published protocol is provided in the section “Differences between protocol and review” of the review’s full version published in the Cochrane Database of Systematic Reviews.

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