Sugar Sweetened Beverages Impact on Body Mass Index: A Systematic Review and Meta-analysis

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Abstract

The increasing trends towards overweight and obesity are similar worldwide and in Thailand. The consumption of sugary sweetened beverages (SSB) can result in increasing risk of obesity. There were systematic reviews with or without meta-analyses (SR/MAs) assessed the association between SSB consumption and body mass index (BMI), which commonly used for defining overweight and obesity. However, their results still controversy with high heterogeneity. To update the previous SR/MAs by adding more recent published individual studies and re-pooled effect of SSB consumption on BMI. The Medline and Scopus databases were search through January 2020. The SR/MAs and any studies that assess the associated between SSB consumption and BMI were included. Data extraction was independently performed by two authors. The random-effects model was applied to pool the effect of SSB consumption on BMI across studies. They were pooled separately by types of study design, types of subjects, and types of SSB report. Twenty-eight SR/MAs with 20 observational studies and 8 intervention studies were included. For observational studies, the increased SSB consumption for every 1 serving was not significantly associated with increasing BMI in girls and boys with the pooled regression coefficients of 0.007 kg/m^2 (95% CI: -0.004, 0.019) and 0.009 kg/m^2 (95% CI: 0.027, 0.045), respectively. The overall pooling effect in children was 0.008 kg/m2 (95% CI: -0.003, 0.019). For intervention studies, the pooled mean difference was -0.111 (95% CI: -0.181, 0.041). This interpreted that children who received intervention programs had lower BMI about 0.111 kg/m2 compared with the control group. The current evidence showed positive association between SSB consumption and BMI in children, although this did not reach to statistical significance. The BMI can be reduced by receiving intervention programs.

Keywords: Sugar Sweetened Beverages, BMI, Systematic Review and Meta-Analysis

Introduction

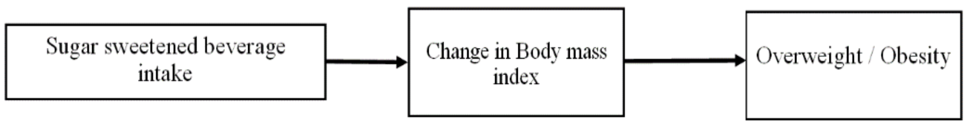
The trends towards overweight and obesity have nearly tripled since 1975. According to the World Health Organization (WHO) reports in 2020, there were 1.9 billion overweight and over 650 million obese in the general population ("World Health Organization. Obesity and overweight.," 2020; WWH, 2014). The Thailand adult obesity rate in 2006 was 6.8% which was the highest in Asia. The prevalence of overweight and obesity was reported at 7.6% and 9% from a national survey in 2011, respectively (Trepatchayakorn, Supornsilchai, Wacharasindhu, Aroonparkmongkol, & Sahakitrungruang, 2014). Obesity is preventable, but it needs high priority monitoring (Jitnarin et al., 2010; WWH, 2014). Changes in dietary lifestyle to urbanization (e.g., drink more sugary sweetened beverages (SSB), consume enriched fat food, and lower physical activity) can result in increased risk of overweight and obesity (Jitnarin et al., 2010). Previous evidence showed an association between SSB consumption and body mass index (BMI) and overweight/ obesity (Ezzati & Riboli, 2013; Forshee, Anderson, & Storey, 2008; Gibson, 2008; Malik, Pan, Willett, & Hu, 2013; Malik, Schulze, & Hu, 2006; Massougbodji, Le Bodo, Fratu, & De Wals, 2014; Mrdjenovic & Levitsky, 2003), but their results are still controversy. There were two systematic review and meta-analyses (SRMA) assessed SSB effects on obesity in children and adolescent including 10 to 15 studies with contrastingly results (add ref.). These may be due to difference in SSB assessment, association evaluation, BMI assessment, duration of study, mean age of subjects, etc.

Most of the studies focused on SSB in children and adolescents, and some focused on special populations such as the elderly or pregnant. There were some narrative reviews (Fardet & Boirie, 2014; Keller & Bucher Della Torre, 2015; Massougbodji et al., 2014; Monasta et al., 2010), systematic reviews (SRs) (Althuis & Weed, 2013; Gibson, 2008; Gomez-Miranda, Jimenez-Cruz, & Bacardi-Gascon, 2013; Jimenez-Cruz, Gomez-Miranda, & Bacardi-Gascon, 2013; Malik et al., 2006; Rao et al., 2015) and meta-analyses (MAs) (Forshee et al., 2008; Malik et al., 2013) of association between SSB and BMI. Among MAs (Forshee et al., 2008; Malik et al., 2013), they pooled the different interventional effects′ sizes, high heterogeneity which were inconsistent between subgroups, with inadequate exploration of confounders or effect modifiers in analysis, together with the possibility of publication bias, so the conclusion could not be drawn. Our aim to clarify the impact of SSB on BMI. We therefore updated previous MAs by adding more recent published individual studies and pooled SSB effects on BMI.

Objectives

Our objective was to update the previous SR/MAs and re-pool for the association between the consumption of SSBs and BMI.

Concept theory framework



Materials and Methods

A review protocol was developed based on PRISMA guideline and it was registered at PROSPERO (CRD42017065459). The protocol was originally designed for assessing effects of SSB consumption on BMI.

Selection of studies

The studies were identified from Medline via PubMed and Scopus since August 2010 to January 2020. The search term and strategies were constructed based on PICO which described in appendices A. The SRs, MAs, and review of systematic and meta-analysis (RSRMA) were selected if they assessed the association between SSB consumption and BMI in any human subjects. The individual studies from the selected SRs, MAs, and RSRMA were included in the analysis.

Studies were excluded if they had insufficient data for analysis after 3 attempts to contact the authors, or if published in languages that the authors could not translate.

Study factors

Our interested factor was SSBs consumption which included products that contained added, naturally derived caloric sweeteners such as sucrose (50% glucose, 50% fructose), and high fructose corn syrup (45% glucose, 55% fructose). These SSBs included fruit juice concentrates, carbonated soft drinks, sport drinks, energy drinks, iced tea, punch, cordial, squash, lemonade, and soda. Fruit juice was classified as the natural non-added sugar or the added sugar drink.

The intervention could be the SSB or the educational program which encouraged subjects to reduce or increase SSB intake.

Outcomes of interest

We considered BMI outcomes, which were measured and defined according to the original included studies by self-report, or official measurement at follow up time. BMI was calculated as the weight in kilograms divided by the square of the height in meters.

Data extraction

Two reviewers (SC and VK) independently extracted the data using the same data record form. We extracted information for general characteristics, age, prior BMI, percent female, percent Caucasian, and physical activity. Type of exposures/interventions and outcome were also extracted.

Mean and standard deviation (SD) between exposure/intervention vs non-exposure/non-intervention to SSBs of actual BMI in any form (BMI z-score, BMI- Standard Deviation Score (BMI-SDS)) were extracted. The regression coefficients or correlation coefficients with standard error (SE) of the association between dependent variable (BMI) and independent variable (SSBs) were extracted for data pooling. For those coefficients of SSB using different units, we re-scaled them using standard serving size (355 ml. or 12 oz.) per day to be consistent serving size. Disagreements were discussed and resolved by the third author (AT).

Risk of bias assessment

Author team (SC, WN, VK, and TU) independently assessed the quality of the studies. Cohort studies were assessed using the 8-item Newcastle-Ottawa Scale (NOS) (Zeng et al., 2015). which captures 3 domains: selection, comparability, and outcome. The Cochrane collaboration tool for assessing risk of bias (Higgins et al., 2011) was used for assessment of RCTs in 6 domains, including selection bias, performance bias, attrition bias, detection bias, reporting bias, and other sources of bias. Each was graded as 'Low risk' of bias, 'High risk' of bias, or 'Unclear risk' of bias. Any disagreements were discussed between both teams and third reviewer (AT).

Statistical analysis

Observational and intervention studies were pooled separately. The unstandardized mean differences (USMD) and their 95% confidence interval (CI) between SSB exposure/ intervention and non-exposure/non-intervention were pooled across studies. If studies did not report individual means, but instead provided regression or correlation coefficients and SE, these were used instead.

Heterogeneity was assessed by Cochrane's Q test and the I^2 statistic. The random-effects model was applied if heterogeneity was present otherwise a fixed-effect model was applied.

Subgroup analysis was subsequently performed according to types of study design (observational or intervention studies), types of subjects (children or adult), and types of report SSB (actual mean or regression coefficient). Publication bias was considered present if the funnel plot showed asymmetry or the p value from Egger's test was less than 0.05. The contour enhance funnel plot was used to distinguish whether asymmetry was due to publication bias or heterogeneity. All analyses were performed using STATA version 15 (Stata Corp., College Station, Texas).

Results

We identified 6,916 and 5,390 studies from Medline and Scopus, respectively (see Figure 1). The 6,806 studies were duplicates and 5,444 were not eligible leaving 56 SR/MAs for consideration. Thirty SRs/MAs finally met our inclusion criteria consisting of 16 SRs/MAs for BMI outcome (13 SRs+3 MAs).

Three SRs and 2 MAs were additionally identified from 4 previous SRs (Fardet & Boirie, 2014; Keller & Bucher Della Torre, 2015; Massougbodji et al., 2014; Monasta et al., 2010), which resulted in 16 SRs (Adam Drewnowski, 2007; Althuis & Weed, 2013; Boyle, Koechlin, & Autier, 2014; Clabaugh & Neuberger, 2011; Dennis, Flack, & Davy, 2009; Emily Wolff, 2008; Gibson, 2008; Gomez-Miranda et al., 2013; Jimenez-Cruz et al., 2013; Libuda & Kersting, 2009; Luger et al., 2017; Malik et al., 2006; Olsen & Heitmann, 2009; Perez-Morales, Bacardi-Gascon, & Jimenez-Cruz, 2013; Rao et al., 2015; Woodward-Lopez, Kao, & Ritchie, 2011) and 5 MAs (Forshee et al., 2008; Kaiser et al., 2013; Lenny R. Vartanian, 2007; Malik et al., 2013; Mattes, Shikany, Kaiser, & Allison, 2011) for final consideration, see Figure 3. Titles and abstracts of 892 individual studies that were included in these SRs and MAs were screened, and only 139 individual studies were retrieved for full texts, but only 28 individual studies (20 observational studies and 8 interventional studies) finally met our inclusion criteria for pooling.

Characteristics of included studies

Among BMI-observational studies, 15, 3, and 2 studies were conducted in children, adults, and mixed children and adults, respectively. Characteristics of studies of these shown in Table 1. Their interested outcomes were reported differently. We mainly grouped into observational and intervention studies and classified age group into childhood, adulthood (see Figure 3).

Risk of bias assessment

Quality assessment of observational studies were described in supplementary, appendices B (Table S1). Among 15 studies, there were 9 studies (60%) that not follow up enough for the outcome and 10 studies that inadequate follow up of the cohorts. All of them were low risk in term of selection of study and comparability.

The risk of bias assessment for 8 intervention studies were reported in supplementary, appendices B (Table S2). Five studies had low risk of bias for random sequence generation. Most of studies (7/8) had low risk of selection bias. All studies had low risk of bias for incomplete outcome data addressed.

Observational studies

The regression correlation coefficients in SSB consumption were reported in 4 studies involving 38,746 girls, and these were pooled using a random-effect model yielding a non-significant pooled regression coefficient (95% CI) of 0.007 (-0.004, 0.019) with moderate heterogeneity (I^2 of 38.8%, Chi-square= 4.91, d.f. = 3, P = 0.179), see Figure 4A. This could interpret that every 1 serving of SSBs increase would increase BMI by 0.007 kg/m^2.

The regression correlation coefficients were also reported in 14,637 boys from 3 studies. These were then pooled using a random-effect model, which resulted in a non-significant pooled regression coefficient (95% CI) of 0.009 (-0.027, 0.045) with moderate heterogeneity (I^2 = 47.2 %; Chi-square= 3.79, d.f. = 2, P = 0.150), see Figure 4A. This could be interpreted that every 1 serving of SSBs increase would relate with increasing BMI by 0.009 kg/m^2. Results of pooling regression correlation coefficients in girls and boys were not much different. Therefore, we also estimated the overall effect by pooling regression correlation coefficients across gender, yielding a non-significant pooled regression coefficient (95% CI) of 0.008 (-0.003, 0.019) with moderate heterogeneity (I^2 of 32.2%, Chi-square= 8.85, d.f. = 6, P = 0.182), see Figure 4A. This could be interpreted that every 1 serving of SSBs increased would relate with increasing BMI by 0.008 kg/m^2.

Publication bias for overall gender pooling was assessed by the Egger's tests indicating no evidence of asymmetry (coefficient = 0.0077, SE = 0.007, P = 0.976). This corresponded with a funnel plot (see Supplementary appendices C: Supplementary Figure S1).

Among 3 studies in fruit juice consumption involving 16,342 girls, the pooled regression correlation coefficient using a random-effect model was 0.001 (95% CI: -0.009, 0.011) with no heterogeneity (I^2 of 0 %, Chi-square= 1.34, d.f. = 2, P = 0.513), see Figure 4B. This could be interpreted that every 1 serving of SSBs increase would relate with increasing BMI by 0.001 kg/m^2 but this was not significant.

A funnel plot was constructed suggesting no evidence of asymmetry (see Appendices C: Supplementary Figure S2), which contrasted with the Egger's tests (coefficient = 0.020, SE = 0.002, P = 0.069). A contour-enhanced funnel plot showed missing studies in significant area (see Appendices C: Supplementary Figure S3) indicating there was publication bias of the positive studies.

Intervention studies

Four studies compared mean BMI changes between the intervention and control groups involving 2,111 children. The intervention programs included education and knowledge about SSBs, motivation to reduce consumption, and encouragement to consume more of sugar free SSBs.

Mean differences were then pooled across studies yielding a non-significant pooled mean difference of -0.111 (95% CI: -0.181, 0.041) with moderate heterogeneity (I^2 of 54.3%), see Figure 5. This could be interpreted that children who received intervention programs had lower BMI change about 0.11 kg/m^2 compared with the control group.

For publication bias assessment, the Egger's tests were not significant (coefficient = -0.105, SE = 0.049, P = 0.882), but the funnel plot showed asymmetry pattern (see Supplementary appendices C: Supplementary Figure S4). Therefore, a contour-enhanced funnel plot was constructed and showed that 3 studies fell in significant area whereas only 1 study was in non-significant area (see Appendices C: Supplementary Figure S5). Asymmetry might be due to heterogeneity not publication bias.

Discussion

We conducted a review of reviews by including a total of 33 previous SRs/MAs. Of them, 21 and 14 SRs/MAs with 28 and 15 individual studies focused on BMI. For every 1 serving of SSB, increased SSB consumption was not significantly association with BMI in boys and girls with the pooled regression coefficients of 0.007 kg/m^2 and 0.009 kg/m^2. Another beverage consumption was fruit juice, and for every increase of 1 serving of fruit juice was also not significantly associated with BMI with the pooled regression coefficients of 0.001 kg/m^2. However, there was publication bias about the positive finding studies.

Several evidences showed similar effect in human body between SSB and fruit juices (Gibson, 2008; Olsen & Heitmann, 2009; Rao et al., 2015). They contain the same number of calories, possess the sweetness, and are similarly absorbed through the human digestive system. There is some effect from fructose and glucose sugar in animal studies, but not in human (Fardet & Boirie, 2014; Singh et al., 2015). Most studies measured BMI correlation by regression correlation, to find the effect of every 1 serving of SSB on increased BMI. Our findings in BMI correlation from SSBs and fruit juices were similar in small effect. Therefore, to gain causal relationship from correlation may not possible. Even though there were some studies which tried to reduce bias by separating type of drinks, but they did not clearly define the differentiated criteria such as fruit juices and fruit flavored non-carbonated drink.

For the intervention, we found not only the SSB intake intervention compared with water or artificial drink, but also the educational program for decreasing SSB consumption. The studies we found had different interventions, so we subgrouped the consistency intervention and pooled. The result showed that for the children who went into the intervention, their BMI decreased 0.11 kg/ m^2.

Our finding from the intervention studies (encourage to reduce the SSB consumption or educate children to reduce intake), the total of available evidence showed a pooled BMI change in intervention group reduction compared with the control group and the difference between intervention and control group showed negative relationship although with high heterogeneity, but it to be a very effective method for reducing SSB consumption. Most of the included trials were behavioral modification (e.g., education programs), which are the effective procedure for evaluating for policy decisions. The follow up time was 6.25-24 months which was quite a long enough time to change the behavior, although some research reported the average period for behavioral change was 21 days (0.7 months) (Ezzati & Riboli, 2013).

The strength of our study was the classified statistic parameter and updating the review of quality studies that were included in previous systematic reviews and meta-analyses and review of meta-analyses and systematic reviews. We used the utility of statistic parameter to classify into the same group of parameters which mainly represented the effect of regression correlation. For our limitation, due to secondary data from trials which were different in units and definition of serving size and frequency. According to the result of subgroup analysis, we had the inadequate exploration of confounders or effect modifiers in the analysis. We suggest exploring more for the other possible confounders or effects which link to the outcomes that link to cardiovascular disease or major cardiovascular events.

The current evidence shows that the relation between SSBs and BMI is very small. The intervention program was an interesting tool for decreasing the BMI which may lead to reduce the overweight or obesity risk. According to our study SSB consumption was associated with raised BMI which can lead to a non-communicable disease which is preventable. In order to encourage children to decrease consumption of SSBs, the program intervention has shown the good outcome, so the policy maker should use this information to implement for society for reducing non-communicable disease.

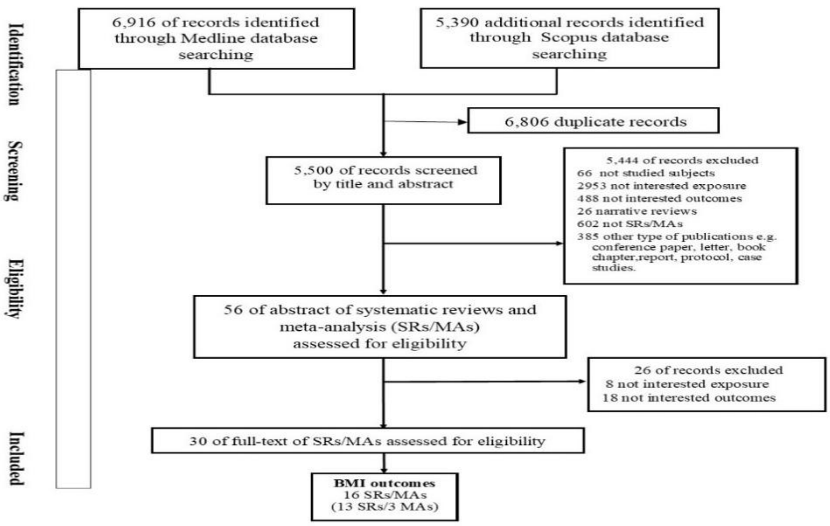


Figure 1 Flow chart selection of systematic reviews and meta-analysis

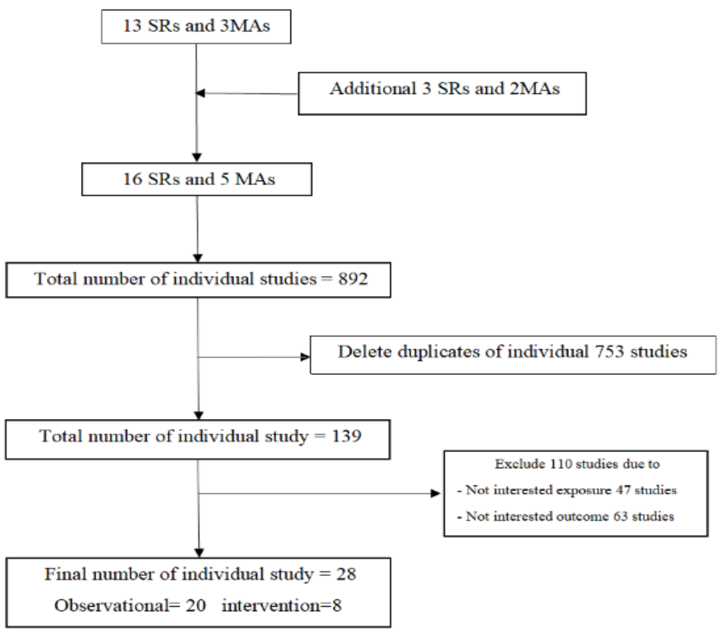


Figure 2 Flow chart for study selection of BMI outcome

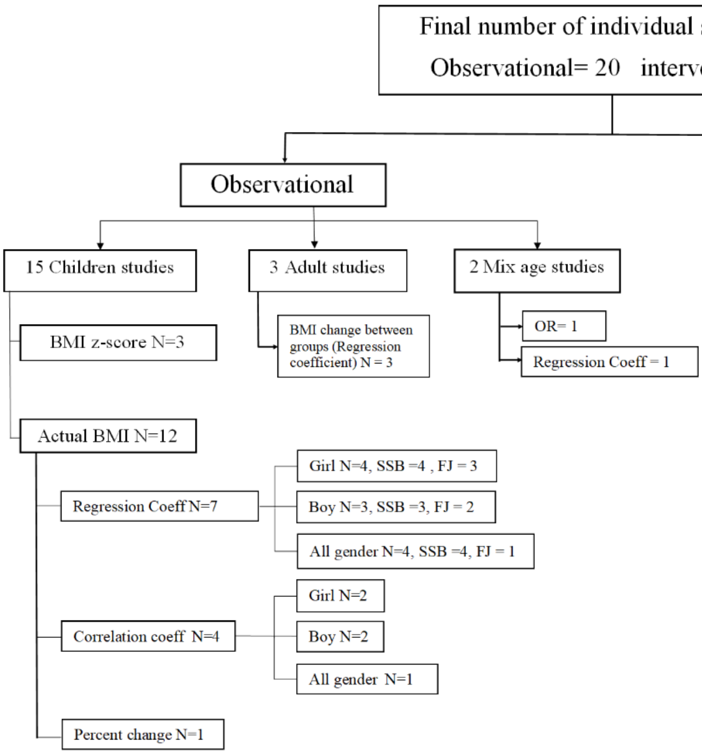


Figure 3 Flow chart for reporting according to study design and type of reporting outcome

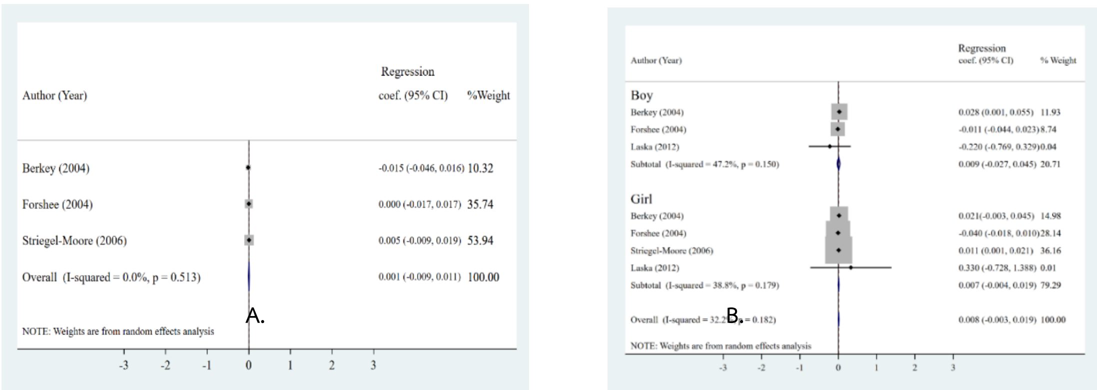


Figure 4 Forest plots of pooling BMI regression correlation coefficient from observational studies

A) SSBs in both gender B) FJ in girl

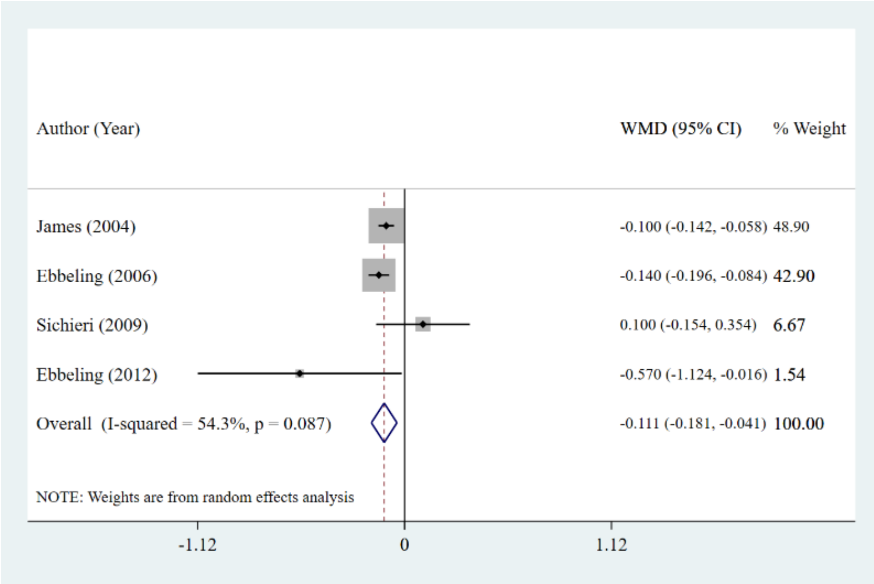


Figure 5 Forest plots of pooling mean different of BMI change in children intervention studies

Table 1 Characteristics of included observational studies in BMI outcome

Author	Year	Country	Setting	Study Design	Exposure	Type Of Drink	% Girl	% Caucasian	Mean Age	No. of Subjects	Time of study (months)	Outcomes	Note
Children													
Giammattei	2003	USA	School	Cross sectional	Intake of beverage	SSB	51.6 8	48.83	12.57(±0. 59)	385	-	BMI z-score Regression coefficient	
Berkey	2004	USA	Commu nity	Cohort	Intake of beverage	SSB, FJ	56.8 9	94.7	9 (±1.35)	11755	12	Regression coefficient	Outcome separate in boy and girl
Cullen	2004	USA	Commu nity	Cross sectional	Intake of beverage	SSB	100	0	9 (±1.35)	147	-	Correlation coefficient	Report only girl
Forshee	2004	USA	School	Cross sectional	Intake of beverage	SSB,FJ	48.5	66.1	14	2216	-	Regression coefficient	Outcome separate in boy and girl
Newby	2004	USA	Commu nity	Cohort	Intake of beverage	SSB, FJ	49.8 1	83.5	2.9 (±0.7)	609	12	Regression coefficient	
Striegel-Moore	2006	USA	Commu nity	Cohort	Intake of beverage	SSB, FJ	100	48.96	13 (±1.97)	2371	120	Regression coefficient	Report only girl
Lim	2009	USA	Commu nity	Cohort	Intake of beverage	SSB, FJ	51.6	0	4(±0.61)	365	24	BMI z-score Regression coefficient	
Vanselow	2009	USA	Commu nity	Cohort	Intake of beverage	SSB, FJ	55.0 1	62.9	14.9 (±0.1)	1325	60	Regression coefficient	
Collison	2010	Saudi Arabia	School	Cross sectional	Intake of beverage	SSB	46.6 4	0	14.5(±2.0 3)	9433	-	Correlation coefficient	Report only boy
Laska	2012	USA	Commu nity	Cohort	Intake of beverage	SSB	50	87.8	14.6 (±1.83)	666	24	Regression coefficient	Report all gender and separate in boy and girl

Table 1 Characteristics of included observational studies in BMI outcome (cont.)

Author	Year	Country	Setting	Study Design	Exposure	Type Of Drink	% Girl	% Caucasian	Mean Age	No. of Subjects	Time of study (months)	Outcomes	Note
Children													
Ambrosini	2013	UK	Community	Cohort	Intake of beverage	SSB	48	100	14(±0.2)	706	36	Percent change	Outcome separate in boy and girl
Field	2014	USA	Community	Cohort	Intake of beverage	SSB	54.52	100	12.9(±1.8)	7559	48	Correlation coefficient	Outcome separate in boy and girl
Zheng	2014	Denmark	Community	Cohort	Intake of beverage	SSB	50	100	9.6(±0.3)	37	72	Regression coefficient	
Karadavut	2017	Turkey	School	Cross sectional	Intake of beverage	SSB	50	100	14 (±0.83)	600	-	Correlation coefficient	
Lewis	2019	USA	Community	Cross sectional	Intake of beverage	SSB	49.5	35	1 (±0.25)	572	12	BMI z-score Regression coefficient	
Adult													
Schulze	2004	USA	Community	Cohort	SSB	100	100	35(±4.9)	2340	60	BMI change between groups (Regression coefficient)		
Vorster	2014	South African	Community	Cohort	SSB	66.9	0	50.6(±10.2)	1233	60	BMI change between groups (Regression coefficient)		
Garduno-Alanis	2020	Czech, Russia, Poland	Community	Cohort	SSB,FJ	53	100	60(±1.67)	2738	36	BMI change between groups (Regression coefficient)		

SSB- Sugar Sweetened beverages, FJ- Fruit juices, BMI- Body mass index

Table 1 Characteristics of included observational studies in BMI outcome (cont.)

Author	Year	Country	Setting	Study Design	Type Of Drink	% Girl	% Caucasian	Mean Age	No. of Subjects	Time of study (months)	Outcomes	Note
Mixed children and adult												
Nissinen	2009	Finland	Community	Cohort	SSB	54.89	100	10.7-31.7	2139	252	Regression coefficient	Outcome separate in boy and girl
Chaves	2018	Brazil	Community	Cross sectional	SSB	52.85	0	>20 yr	2419	-	OR of BMI z score	Outcome separate in boy and girl

SSB- Sugar Sweetened beverages, FJ- Fruit juices, BMI- Body mass index

Table 2 Characteristics of interventional studies

Author	Year	Country	Setting	Intervention	Type of Drink	%Girl	% Caucasian	Mean Age	No. of Subjects	Time of study (months)	Outcomes
Children											
James	2004	UK	School	Pgm	SSB	49.68	100	8.7 (±0.9)	644	12	actual BMI, actual BMI z score, BMI change, BMI z score change, ∆BMI Exp_ control, ∆BMI z score Exp_ control, BMI correlation, BMI z score correlation
Ebbeling	2006	USA	School	Pgm	SSB	54.36	36	15.5 (±2.44)	103	6.25	BMI change, ∆BMI Exp_ control
Sichieri	2009	Brazil	School	Pgm	SSB	52.85	42.05	10.5 (±1.63)	1140	10	BMI change, ∆BMI Exp_ control, BMI Correlation
De Ruyter	2012	Netherlands	Community	Intake of beverage	SSB	47	78	8.2 (±1.8)	641	18	∆BMI z score Exp_ control, actual BMI z score
Ebbeling	2012	USA	Community	Pgm	SSB	44.64	55.35	15.3 (±0.7)	224	24	Actual BMI, BMI change, ∆BMI Exp_ control
Adult											
Raben	2002	Denmark	Community	Intake of beverage	SSB	85.36	100	33.3(±2)	41	2.5	BMI change between groups (Regression Coefficient)
Reid	2007	UK	Community	Intake of beverage	SSB	100	100	31.8(±9.1)	133	1	BMI change before and after receive intervention
Zuanazzi	2019	Brazil	Community	Intake of beverage	FJ	100	100	58.5(±4.25)	25	1	BMI change before and after receive intervention

SSB- Sugar Sweetened beverages, FJ- Fruit juices, BMI- Body mass index, Pgm- Program education

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