Effects of Soft Drink Consumption on Nutrition and Health: A Systematic Review and Meta-Analysis

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In a meta-analysis of 88 studies, we examined the association between soft drink consumption and nutrition and health outcomes. We found clear associations of soft drink intake with increased energy intake and body weight. Soft drink intake also was associated with lower intakes of milk, calcium, and other nutrients and with an increased risk of several medical problems (e.g., diabetes).

Study design significantly influenced results: larger effect sizes were observed in studies with stronger methods (longitudinal and experimental vs cross-sectional studies). Several other factors also moderated effect sizes (e.g., gender, age, beverage type). Finally, studies funded by the food industry reported significantly smaller effects than did non–industry-funded studies. Recommendations to reduce population soft drink consumption are strongly supported by the available science. (*Am J Public Health.* 2007;97:667–675. doi:10.2105/AJPH.2005.083782)

Soft drink consumption has become a highly visible and controversial public health and public policy issue. Soft drinks are viewed by many as a major contributor to obesity and related health problems and have consequently been targeted as a means to help curtail the rising prevalence of obesity, particularly among children. Soft drinks have been banned from schools in Britain and France, and in the United States, school systems as large as those in Los Angeles, Philadelphia, and Miami have banned or severely limited soft drink sales. Many US states have considered statewide bans or limits on soft drink sales in schools, with California passing such legislation in 2005. A key question is whether actions taken to decrease soft drink consumption are warranted given the available science and whether decreasing population consumption of soft drinks would benefit public health.

The issue is not new. In 1942 the American Medical Association mentioned soft drinks specifically in a strong recommendation to limit intake of added sugar.[1] At that time, annual US production of carbonated soft drinks was 90 8-oz (240-mL) servings per person; by 2000 this number had risen to more than 600 servings.[2] In the intervening years, controversy arose over several fundamental concerns: whether these beverages lead to energy overconsumption; whether they displace other foods and beverages and, hence, nutrients; whether they contribute to diseases such as obesity and diabetes; and whether soft drink marketing practices represent commercial exploitation of children.[3–5]

The industry trade association in the United States (the American Beverage Association, formerly the National Soft Drink Association) counters nutrition concerns with several key points: (1) the science linking soft drink consumption to negative health outcomes is flawed or insufficient, (2) soft drinks are a good source of hydration, (3) soft drink sales in schools help education by providing needed funding, (4) physical activity is more important than food intake, and (5) it is unfair to "pick on" soft drinks because there are many causes of obesity and there are no "good" or "bad" foods. Similar positions have been taken by other trade associations such as the British Soft Drinks Association and the Australian Beverages Council.

Legislative and legal discussions focusing on soft drink sales often take place on political and philosophical grounds with scant attention to existing science. Our objectives were to review the available science, examine studies that involved the use of a variety of methods, and address whether soft drink consumption is associated with increased energy intake, increased body weight, displacement of nutrients, and increased risk of chronic diseases.

METHODS

We focused on research investigating the effects of sugar-sweetened beverages; diet and artificially sweetened beverages are noted only in certain cases for comparison purposes. We conducted a computer search through MEDLINE and PsycINFO using the key terms "soft drink," "soda," and "sweetened beverage." We identified articles that assessed the association of soft drink consumption with 4 primary outcomes (energy intake, body weight, milk intake, and calcium intake) and 2 secondary outcomes (nutrition and health). We identified additional articles by searching each article's reference section and the Web of Science database. Finally, we contacted the authors of each included article with a request for unpublished or in-press work, and we asked each author to forward our request to other researchers who might have relevant work. Our searches yielded a total of 88 articles that were included in the present analysis.

There is a great deal of variability in research methods in this literature. Studies vary in their design (i.e., cross-sectional, longitudinal, or experimental studies), sample characteristics (e.g., male vs female, adults vs children), and operational definitions of independent and dependent variables. Because such heterogeneity of research methods is likely to produce heterogeneity of effect sizes across studies (an effect size represents the magnitude of the relationship between 2 variables), we took 2 steps to assess the impact of research method on outcome.

Initially, for each primary outcome (energy intake, body weight, milk intake, and calcium intake), we assessed the degree of heterogeneity of effect sizes by testing the significance of the Q statistic, which is the sum of the squared deviations of each effect size from the overall weighted mean effect size. We did not assess the degree of heterogeneity for secondary outcomes (nutrition and health) because there were relatively few studies in these domains. Our analysis of primary outcomes revealed a significant degree of heterogeneity of effect sizes in each case, and thus we separated the studies according to research design. This procedure reduces the likelihood of aggregating effect-size estimates across heterogeneous studies. Moreover, some research designs are viewed as more powerful than others. Cross-sectional studies represent the weakest design, because such studies cannot determine causality. Longitudinal designs are considered stronger, but experimental designs are the strongest test of causal relationships. Thus, separating studies according to type of design allowed us to examine effect magnitudes as a function of strength of research design.

We further explored variability in effect sizes by examining a number of potential moderator variables, including (1) population studied (children and adolescents vs adults), (2) gender of participants (only male, only female, or male and female combined), (3) type of beverage (sugar-sweetened carbonated soft drinks vs a mix of sugar-sweetened and diet beverages), (4) whether the reported results were adjusted for covariates (e.g., age, gender, ethnicity, activity level), (5) assessment method (self-reports vs observations or measurements), and (6) presence or absence of food industry funding. A study was coded as "industry funded" if the authors acknowledged support from food companies, beverage companies, or trade associations. Articles that did not report a funding source or cited support from other sources (e.g., pharmaceutical industry, university, foundation, or government grants) were coded as "non–industry funded."

We calculated average effect sizes (*r* values) using Comprehensive Meta-Analysis version x2 (Biostat, Englewood, NJ). In most cases, we entered data in the form in which they appeared in each individual study, including group means and standard deviations, correlation coefficients, *t* values, *P* values, and odds ratios and confidence intervals. In certain cases, it was necessary to manually calculate effect sizes. For example, when means for more than 2 groups were presented (e.g., low, moderate, and high soft drink consumption), we used the formulas for 1-way contrasts described by Rosenthal et al.[6] In other cases, odds ratios were reported with uneven confidence intervals (as a result of rounding), and effect sizes were calculated directly from the odds ratio according to the method described by Chinn.[7]

When data from different subgroups were presented separately (e.g., data for male and female participants were presented independently), we calculated effect sizes separately for each subgroup. In the case of studies that reported multiple measures of a particular construct (e.g., both body weight and body mass index [BMI]), we computed the average effect size of the reported measures. When there was extraordinary variability in sample sizes across studies, we employed the conservative approach of limiting the sample size of the largest study in a particular domain (e.g., cross-sectional studies of energy intake) to the maximum sample size of the other studies in that domain. This approach ensured that the calculated average effect size would not be dominated by a single study. We considered an effect size of 0.10 or less as small, an effect size of 0.25 as medium, and an effect size of 0.40 or above as large.[8]

To assess the presence of publication bias, we computed a "fail-safe N" for each of the main outcomes; this value is an estimate of the number of unretrieved or unpublished studies with null results that would be required to render the observed effect nonsignificant. Rosenthal[9] suggested that a fail-safe N greater than $5k+10$ (with k being the number of studies included in the analysis) indicates a robust effect; in the present analyses, each fail-safe N far exceeded Rosenthal's recommendation, suggesting a low probability of publication bias.

RESULTS

Soft Drink Consumption and Energy Intake

The overall effect size (*r*) across all studies for the relation between soft drink consumption and energy intake was 0.16 ($P<.001$, $Q_{46}=715.46$, fail-safe N=9726). Because there was a significant degree of heterogeneity among the effect sizes, we separated studies according to type of research design. Effect sizes for soft drink consumption and energy intake are shown in Table 1.

Of the 12 cross-sectional studies examining the relation between soft drink consumption and energy intake, 10 reported a significant positive association,[10–19] 1 reported mixed results,[20] and 1 reported no statistically significant effect.[21] Two studies showed that the increase in energy intake associated with soft drink consumption was greater than what could be explained by consumption of the beverages alone,[11,17] suggesting that such beverages might stimulate appetite or suppress satiety, perhaps because of a high glycemic index (foods with a high glycemic index produce a rapid rise in blood sugar).[22] The average effect size of the association between soft drink consumption and energy intake across all cross-sectional studies was 0.13 ($P<.001$; $Q_{15}=433.67$, $P<.001$).

The 5 longitudinal studies that we identified all reported positive associations between soft drink consumption and overall energy intake.[17,23–26] The average effect size for these studies was 0.24 ($P<.001$; $Q_6=109.11$, $P<.001$).

Four long-term experimental studies in which participants consumed soft drinks for between 3 and 10 weeks showed that individuals failed to compensate for the extra energy consumed in the form of sugar-sweetened beverages in that they did not reduce the rest of their food energy intake, resulting in a greater total daily energy intake.[27–30] One study revealed that participants consumed 17% more energy than in their typical diet even after the energy from the soft drinks they consumed had been taken into account,[27] suggesting again that soft drinks may influence other aspects of dietary intake. The average effect size was 0.30 ($P<.001$; $Q_4=2.37$, $P=.667$). Because the Q statistic was not statistically significant, we did not investigate moderators for long-term experimental studies.

Findings from short-term experimental studies (i.e., those examining energy intake over the course of a subsequent meal or a single day) were mixed. Of 12 studies, 5 reported that individuals who consumed soft drinks consequently took in a greater amount of total energy (food energy plus beverage energy) than did those who consumed water.[31–35] One study also revealed higher-than-expected energy intakes among

TABLE 1—Average Energy Intake Effect Sizes, by Type of Research Design

	Cross-Sectional		Longitudinal		Experimental (Short)		Overall	
	r (95% CI)	No.[a]	r (95% CI)	No.[a]	r (95% CI)	No.[a]	r (95% CI)	No.[a]
Gender								
Male	0.06* (0.04, 0.08)	2	0.27 (0.11, 0.42)	1	0.16 (0.04, 0.27)	6	0.07* (0.05, 0.09)	10
Female	0.16* (0.14, 0.17)	3	0.25 (0.23, 0.27)	3	0.32 (0.21, 0.41)	4	0.19* (0.18, 0.20)	10
Mixed	0.14* (0.12, 0.15)	8	0.20 (0.14, 0.26)	2	0.10 (−0.04, 0.24)	4	0.14* (0.13, 0.16)	17
Age group								
Children	0.08* (0.06, 0.09)	10	0.09* (0.05, 0.13)	2	0.00 (−0.31, 0.31)	1	0.08* (0.07, 0.09)	13
Adults	0.28* (0.26, 0.30)	2	0.29* (0.27, 0.31)	3	0.22 (0.15, 0.29)	11	0.28* (0.27, 0.30)	19
Type of beverage								
Sugared soda	0.23* (0.21, 0.24)	7	0.24 (0.23, 0.26)	4	0.33* (0.23, 0.42)	4	0.24* (0.23, 0.25)	16
Mixed/other	0.06* (0.05, 0.07)	5	0.38 (0.21, 0.53)	1	0.10* (0.00, 0.20)	8	0.06* (0.05, 0.08)	16
Soda intake								
Self-reported	0.13 (0.12, 0.14)	12	0.24 (0.23, 0.26)	4	...	...	0.16* (0.15, 0.16)	15
Measured	...	...	0.38 (0.21, 0.53)	1	0.21 (0.14, 0.28)	12	0.25* (0.20, 0.30)	17
Energy intake								
Self-reported	0.13 (0.12, 0.14)	12	0.24 (0.23, 0.26)	5	0.09 (−0.07, 0.24)	3	0.16 (0.15, 0.16)	22
Measured	...	...	...	...	0.24 (0.16, 0.31)	9	0.24 (0.17, 0.31)	10
Adjusted values								
No	0.15 (0.13, 0.18)	7	0.19 (0.14, 0.25)	3	0.21 (0.14, 0.28)	12	0.17 (0.15, 0.20)	26
Yes	0.12 (0.11, 0.14)	5	0.25 (0.23, 0.27)	2	...	...	0.15 (0.15, 0.16)	6
Industry funded								
No	0.21* (0.20, 0.23)	9	0.25 (0.23, 0.27)	4	0.25 (0.16, 0.33)	7	0.23* (0.22, 0.24)	22
Yes	0.04* (0.03, 0.06)	3	0.18 (0.11, 0.24)	1	0.16 (0.06, 0.27)	5	0.05* (0.04, 0.07)	10

Note. CI = confidence interval. Because some studies reported both cross-sectional and longitudinal data, and because long-term experimental studies are not displayed, the numbers for the Overall column do not necessarily equal the sum of the numbers for the other columns.
[a]Number of studies included in the analysis.
*$P < .0056$ (adjusted for multiple comparisons) for differences in effect sizes within each column and research design variable.

participants given the energy they consumed from soft drinks.[34] By contrast, 5 other studies reported that participants compensated at a subsequent meal for energy consumed from beverages.[36–40] Still others reported mixed results, depending, for example, on how long before lunch participants consumed soft drinks.[41,42] The average effect size for short-term experimental studies was 0.21 ($P < .001$; $Q_{18} = 37.92$, $P = .004$).

These results, taken together, provide clear and consistent evidence that people do not compensate for the added energy they consume in soft drinks by reducing their intake of other foods, resulting in increased total energy intakes. Not only do people fail to compensate for the energy consumed in soft drinks, but there is also some evidence that the increase in energy intake associated with soft drink consumption is even greater than what can be accounted for by the beverages alone, suggesting that food energy intake is also higher. The largest effect sizes were observed in long-term experimental studies, followed by short-term experimental and longitudinal studies. The smallest effects were found in cross-sectional studies. Further testing of moderators revealed significantly larger effect sizes among (1) women, (2) adults, (3) studies focusing on sugar-sweetened soft drinks, and (4) studies not funded by the food industry (Table 1).

Soft Drink Consumption and Body Weight

Research evaluating the relationship between soft drink consumption and body weight is complicated by the fact that researchers operationalize body weight in a number of different ways, even within the same study. When multiple measures of weight were provided in a single study, we calculated the average effect size across those measures. The overall effect size for studies examining the link between soft drink consumption and body weight was 0.08 ($P < .001$; $Q_{47} = 337.73$, $P < .001$, fail-safe $N = 3173$). Because there was a significant degree of effect size heterogeneity, we examined effect sizes separately for each research design. Effect sizes for soft drink consumption and body weight are shown in Table 2.

In cross-sectional studies, outcomes varied depending on how body weight was operationalized. When the focus was on the association between soft drink consumption and BMI, 2 studies reported a significant positive association,[43,44] whereas 9 did not.[10,16,17,45–50] Two studies revealed a positive association between soft drink consumption and body fat percentage,[21,43] but 1 study did not.[51] In addition, 4 studies showed that people's risk of being overweight or obese was positively associated with their soft drink consumption.[43,46,52,53] Other studies reported a positive association between soft drink consumption and body weight[54,55] and ponderal index[18] but not skinfold thickness.[55] Averaged across the different methods of operationalization, the mean effect size was 0.05 ($P < .001$; $Q_{23} = 64.36$, $P < .001$; 1 study[50] was excluded from this analysis because an effect size could not be computed from the available data).

There was some evidence from the longitudinal studies examined that soft drink consumption is associated with weight gain.[11,17,23,54,56] One study showed that soft drink intake was significantly related to 1-year change in body weight among boys but that the association was no longer statistically significant when the analyses controlled for total energy intake.[11] This finding suggests that the association between soft drink consumption and weight change was because of the increase in daily energy intake caused by soft drink consumption. Two other studies reported mixed results depending on how body weight was operationalized,[57,58] and 4 studies reported no association between soft drink intake and BMI or change in BMI.[15,25,26,59] The overall effect size for longitudinal studies was 0.09 ($P < .001$; $Q_{15} = 177.76$, $P < .001$; 1 study[57] was excluded from this analysis because an effect size could not be computed from the available data).

TABLE 2—Effect Sizes for Average Body Weight, by Type of Research Design

	Cross-Sectional		Longitudinal		Experimental (Long)		Overall	
	r (95% CI)	No.[a]	r (95% CI)	No.[a]	r (95% CI)	No.[a]	r (95% CI)	No.[a]
Gender								
Male	0.02* (–0.01, 0.05)	5	0.03* (0.00, 0.05)	2	0.17 (0.01, 0.32)	2	0.03* (0.01, 0.05)	9
Female	0.02* (–0.00, 0.04)	8	0.11* (0.10, 0.13)	5	0.49 (0.17, 0.72)	1	0.09* (0.08, 0.10)	13
Mixed	0.07* (0.06, 0.09)	9	0.04* (0.01, 0.07)	5	0.24 (0.18, 0.30)	5	0.08* (0.06, 0.09)	18
Age group								
Children	0.03* (0.01, 0.04)	13	0.03* (0.01, 0.04)	7	0.29 (0.22, 0.35)	2	0.03* (0.02, 0.04)	22
Adults	0.06* (0.05, 0.08)	5	0.14* (0.13, 0.16)	3	0.15 (0.05, 0.24)	5	0.11* (0.10, 0.12)	11
Type of beverage								
Sugared soda	0.04 (0.03, 0.05)	10	0.13* (0.11, 0.14)	7	0.15 (0.04, 0.25)	4	0.09* (0.08, 0.10)	19
Mixed/other	0.07 (0.04, 0.09)	8	0.03* (0.01, 0.04)	3	0.27 (0.21, 0.34)	3	0.05* (0.04, 0.06)	14
Soda intake								
Self-reported	0.05 (0.03, 0.06)	17	0.09 (0.08, 0.10)	9	0.07 (–0.12, 0.26)	1	0.07 (0.07, 0.08)	25
Measured	0.20 (0.04, 0.35)	1	0.13 (–0.08, 0.33)	1	0.15 (0.05, 0.24)	5	0.16 (0.08, 0.23)	7
Weight								
Self-reported	0.05 (0.03, 0.06)	5	0.10* (0.09, 0.11)	4	...	...	0.08 (0.07, 0.09)	7
Measured	0.06 (0.03, 0.08)	12	0.03* (0.00, 0.06)	6	0.24 (0.18, 0.29)	7	0.06 (0.05, 0.08)	25
Adjusted values								
No	0.06 (0.05, 0.08)	10	0.06 (0.02, 0.09)	4	0.25 (0.20, 0.31)	6	0.08 (0.06, 0.09)	19
Yes	0.03 (0.02, 0.05)	9	0.10 (0.09, 0.11)	6	0.07 (–0.12, 0.26)	1	0.08 (0.07, 0.09)	15
Industry funded								
No	0.06* (0.05, 0.08)	12	0.13* (0.11, 0.14)	8	0.26 (0.20, 0.31)	5	0.10* (0.09, 0.11)	23
Yes	0.02* (0.00, 0.04)	6	0.03* (0.01, 0.04)	2	0.11 (–0.05, 0.26)	2	0.02* (0.01, 0.04)	10

Note. CI = confidence interval. Because some studies reported both cross-sectional and longitudinal data, the numbers for the Overall column do not necessarily equal the sum of the numbers for the other columns.
[a]Number of studies included in the analysis.
*$P<.0056$ (adjusted for multiple comparisons) for differences in effect sizes within each column and research design variable.

We found 7 studies that examined the connection between soft drink intake and body weight in an experimental or intervention context. Five reported a positive association.[27–29,60,61] In 3 of these studies, participants who were given soft drinks to consume gained weight over the course of the experiment. Two intervention studies aimed at decreasing soft drink consumption among high school students showed that students in the intervention groups essentially maintained their weight over the treatment period, whereas those in the control groups exhibited significant weight gain. Two studies reported no statistically significant effect of soft drink consumption on weight gain.[30,62] The average effect size for experimental studies was 0.24 ($P<.001$; $Q_7=24.57$, $P=.001$).

Larger effect sizes were observed in experimental studies than in cross-sectional or longitudinal studies. Also, further testing of moderators revealed that effect sizes were larger among (1) women, (2) adults, (3) studies focusing on sugar-sweetened soft drinks, and (4) studies not funded by the food industry (Table 2).

Soft Drink Consumption and Milk and Calcium Intake

The overall effect size for milk intake was –0.12 ($P<.001$, $Q_{33}=300.43$, $P<.001$, fail-safe N=4048). The overall effect size for calcium intake was –0.04 ($P<.001$; $Q_{28}=368.65$, $P<.001$, fail-safe N=418). Effect sizes for soft drink consumption and milk and calcium intake are shown in Tables 3 and 4, respectively.

Fifteen cross-sectional studies examined the association between soft drink consumption and milk intake; 13 reported that soft drink consumption was associated with lower intakes of milk and dairy products,[10,14–16,19,20,51,54,63–67] 1 reported no statistically significant association,[68] and 1 reported a small positive association between milk intake and soft drink consumption.[69] One study showed that a 1-oz decrease in soft drink consumption was related to approximately a 0.25-oz increase in milk consumption.[63] In other words, reducing soft drink consumption by one 16-oz serving per day would be associated with an increase of approximately 4 oz of milk per day. The average effect size for milk intake was –0.11 ($P<.001$; $Q_{27}=268.33$, $P<.001$).

Calcium intake was also negatively associated with soft drink consumption in several cross-sectional studies,[14,16,19,44,64,65,67–71] but the effect sizes were generally small. In addition, 4 other studies reported positive associations between soft drink consumption and calcium intake,[51,63,69,72] and 1 reported mixed results.[20] Across all studies, the average effect of soft drink consumption was –0.02 ($P=.006$, $Q_{23}=275.51$, $P<.001$).

Results from longitudinal studies were similar to those from cross-sectional studies, but the magnitude of the effects was larger. Five longitudinal studies reported a negative relationship between soft drink intake and intakes of milk and dairy products,[26,59,73–75] and 5 reported a negative relation between soft drink consumption and calcium intake.[23,73,74,76,77] The average effect sizes for milk and calcium intakes were –0.21 ($P<.001$; $Q_5=23.09$, $P<.001$) and –0.13 ($P<.001$; $Q_4=15.22$, $P=.004$), respectively.

For milk intake, significantly larger effect sizes were observed in longitudinal studies and in studies that included a variety of beverages, provided adjusted values, and were not funded by the food industry (Table 3). For calcium intake, larger effect sizes were observed among adults and among studies that included a variety of beverages. In addition, studies funded by the food industry exhibited slight positive effects, whereas studies not funded by the food industry exhibited small negative effects (Table 4).

Soft Drink Consumption and Nutrient Intake

Soft drink consumption also has been examined in relation to a variety of other foods, macronutrients, and micronutrients. In the

TABLE 3—Average Milk Intake Effect Sizes, by Type of Research Design

	Cross-Sectional		Longitudinal		Overall	
	r (95% CI)	No.[a]	*r* (95% CI)	No.[a]	*r* (95% CI)	No.[a]
Gender						
Male	−0.20* (−0.24, −0.16)	2	−0.15 (−0.39, 0.11)	1	−0.20* (−0.24, −0.16)	3
Female	−0.19* (−0.22, −0.16)	4	−0.12 (−0.24, 0.01)	2	−0.19* (−0.22, −0.16)	6
Mixed	−0.10* (−0.11, −0.08)	11	−0.25 (−0.32, −0.17)	3	−0.10* (−0.11, −0.09)	14
Age group						
Children	−0.12 (−0.13, −0.11)	14	−0.21 (−0.27, −0.15)	5	−0.12 (−0.13, −0.11)	19
Adults	−0.09 (−0.12, −0.07)	2	...	...	−0.09 (−0.12, −0.07)	2
Type of beverage						
Sugared soda	−0.06* (−0.08, −0.05)	6	−0.19 (−0.26, −0.10)	2	−0.07* (−0.08, −0.05)	8
Mixed/other	−0.19* (−0.21, −0.17)	9	−0.25 (−0.34, −0.15)	3	−0.19* (−0.21, −0.18)	12
Soda intake						
Self-reported	−0.11 (−0.12, −0.10)	15	−0.17* (−0.23, −0.10)	4	−0.12* (−0.13, −0.11)	19
Measured	...	...	−0.58* (−0.70, −0.43)	1	−0.58* (−0.70, −0.43)	1
Milk intake						
Self-reported	−0.11 (−0.12, −0.10)	15	−0.21 (−0.27, −0.15)	5	−0.12 (−0.13, −0.11)	20
Measured	...	...	...	...	...	...
Adjusted values						
No	−0.09* (−0.10, −0.08)	9	−0.23 (−0.29, −0.16)	4	−0.10* (−0.11, −0.08)	13
Yes	−0.19* (−0.21, −0.16)	6	−0.14 (−0.28, 0.00)	1	−0.18* (−0.21, −0.16)	7
Industry funded						
No	−0.15* (−0.16, −0.13)	9	−0.31 (−0.40, −0.21)	3	−0.15* (−0.16, −0.14)	12
Yes	−0.06* (−0.08, −0.04)	6	−0.15 (−0.23, −0.07)	2	−0.06* (−0.08, −0.05)	8

Note. CI = confidence interval.
[a]Number of studies included in the analysis.
*$P < .0056$ (adjusted for multiple comparisons) for differences in effect sizes within each column and research design variable.

case of many of these outcomes, there were only a small number of studies (and sometimes only a single study). We therefore aggregated effect sizes across all studies without examining the impact of research design or any other potential moderator variables. Thus, these aggregated effects should be interpreted with caution. A complete list of the nutritional variables investigated is available from the authors.

Several studies reported a positive association between soft drink consumption and carbohydrate intake,[13,14,17,19,20,24,27,28,31,35,39] whereas 1 study reported a negative relation[54] and 2 others reported no relation[16,38] (average r=0.13; 4 studies[33,34,41,42] were excluded from the analysis because effect sizes could not be computed from the available data). A few studies highlighted the specific sources of carbohydrate related to soft drink consumption. One study reported that children and adolescents in the highest quartile of soft drink consumption consumed between 122 and 159 g of added sugar, approximately 4 to 5 times the US Department of Agriculture's recommended maximum of added sugar (32 g).[64] Overall associations (r values) of soft drink consumption with added sugar, fructose, and sucrose were 0.18, 0.36, and 0.23, respectively. Other studies revealed a negative association of soft drink consumption with intake of both dietary fiber (r=−0.31) and starch (r=−0.27). Thus, these findings indicate that the increased carbohydrate intake associated with soft drink consumption primarily reflects greater consumption of added sugars.

Soft drink consumption also was associated with decreased intakes of protein (r=−0.14), fruit juice (r=−0.17), fruit (r=−0.09), and riboflavin (r=−0.12), among others. Overall, there was no evidence of an association between soft drink consumption and fat intake, nor was there an association with intake of certain vitamins, including A and B_{12} (all rs<0.01). One study[16] reported a negative association between soft drink consumption and an overall "healthy eating index," and another study[74] reported an overall negative association between soft drink consumption and average adequacy of intake of a variety of vitamins and nutrients.

Soft Drink Consumption and Health Outcomes

A number of studies examined links between soft drink consumption and various health outcomes. We report average effect sizes only when there was more than a single study for a particular outcome.

Perhaps the most striking link between soft drink consumption and health outcomes was the prospective evidence obtained for type 2 diabetes. In a study of 91 249 women followed for 8 years, those who consumed 1 or more servings of soft drink per day were twice as likely as those who consumed less than 1 serving per month to develop diabetes over the course of the study.[17] These effects were only slightly attenuated when various potential confounds, including BMI and energy intake, were controlled. When diet soft drinks replaced sugar-sweetened soft drinks in the analysis, the increased risk was no longer present, suggesting that the risk was specific to sugar-sweetened soft drinks. Another study reported a positive association between soft drink consumption and number of risk factors for metabolic syndrome.[78] These effects also remained when BMI and energy intake were controlled.

Smaller associations were found with a number of other health outcomes. For example, 2 studies linked soft drink consumption with hypocalcemia (average r=0.38),[79,80] and a 30-day follow-up involving a group of patients with hypocalcemia who were asked to refrain from consuming soft drinks revealed a significant increase in serum calcium.[80] In addition, 2 studies reported a small but statistically significant negative association between soft drink consumption and bone mineral density,[51,75] whereas 2 others did not[44,68] (average r=−0.03). An association was also reported between soft drink consumption and increased risk of bone fracture (average r=0.06).[68,81–83] Some research has shown no effect of soft

TABLE 4—Average Calcium Intake Effect Sizes, by Type of Research Design

	Cross-Sectional		Longitudinal		Overall	
	r (95% CI)	No.[a]	r (95% CI)	No.[a]	r (95% CI)	No.[a]
Gender						
Male	0.06 (−0.02, 0.14)	1	−0.14 (−0.18, −0.10)	1	−0.10* (−0.14, −0.07)	2
Female	−0.04 (−0.07, −0.02)	5	−0.13 (−0.16, −0.10)	3	−0.09* (−0.11, −0.07)	8
Mixed	−0.01 (−0.03, 0.00)	9	−0.05 (−0.15, 0.05)	1	−0.01* (−0.03, 0.00)	10
Age group						
Children	−0.01 (−0.02, 0.00)	12	−0.08* (−0.12, −0.04)	3	−0.02* (−0.03, −0.01)	15
Adults	−0.06 (−0.09, −0.03)	3	−0.16* (−0.19, −0.13)	2	−0.12* (−0.14, −0.10)	5
Type of beverage						
Sugared soda	0.05* (0.03, 0.07)	3	−0.13 (−0.16, −0.11)	3	−0.02* (−0.03, −0.00)	6
Mixed/other	−0.07* (−0.08, −0.05)	11	−0.08 (−0.16, −0.00)	2	−0.07* (−0.08, −0.05)	13
Soda intake						
Self-reported	−0.02 (−0.03, −0.01)	14	−0.13 (−0.15, −0.11)	5	−0.04 (−0.05, −0.03)	19
Measured	...	...	...	...	...	...
Calcium intake						
Self-reported	−0.02 (−0.03, −0.01)	14	−0.15* (−0.18, −0.13)	4	−0.04 (−0.05, −0.03)	18
Measured	...	...	−0.08* (−0.12, −0.04)	1	−0.08 (−0.12, −0.04)	1
Adjusted values						
Yes	0.07* (0.04, 0.11)	4	−0.16 (−0.19, −0.13)	2	−0.07 (−0.09, −0.05)	6
No	−0.03* (−0.04, −0.02)	10	−0.08 (−0.12, −0.04)	3	−0.03 (−0.05, −0.02)	13
Industry funded						
Yes	−0.05* (−0.06, −0.03)	9	−0.13 (−0.16, −0.11)	3	−0.07* (−0.09, −0.06)	12
No	0.03* (0.01, 0.05)	5	−0.08 (−0.16, −0.00)	2	0.03* (0.01, 0.05)	7

Note. CI = confidence interval.
[a]Number of studies included in the analysis.
*$P < .0056$ (adjusted for multiple comparisons) for differences in effect sizes within each column and research design variable.

drink consumption on calcium metabolism and urinary excretion of calcium, and it has therefore been suggested that the role of soft drinks in calcium deficiency and reduced bone mineral density is that of displacing other sources of calcium, such as milk.[84,85]

A small positive association was found between soft drink consumption and dental caries[86–89] (r=0.03; 2 studies[90,91] were excluded from the analysis because effect sizes could not be computed from the available data). The association between soft drinks and dental caries was not observed for diet soft drinks.[86] Also, 5 studies reported that soft drink consumption was positively associated with urinary or kidney stones, but 2 studies reported no association (average r=0.05).[76,77,92–96] Two of the 5 studies that found positive associations[76,77] revealed that the effect of soft drink intake was no longer significant after other risk factors such as calcium, potassium, and sucrose intake had been controlled, suggesting that the effect of soft drink consumption on urinary stones may be a consequence of its influence on these other risk factors.

A 10-week experimental study showed that individuals who consumed sucrose-sweetened beverages exhibited an increase in both systolic and diastolic blood pressure over the course of the study, whereas individuals who consumed artificially sweetened beverages exhibited a decrease in blood pressure.[28] Also, a cross-sectional study reported an association between caffeinated soft drink consumption and systolic blood pressure among African Americans but not European Americans.[97] By contrast, another cross-sectional study revealed small negative correlations between soft drink intake and both systolic and diastolic blood pressure.[18] Finally, 1 study reported a positive association between soft drink consumption and risk of hypertension.[98]

DISCUSSION

Intake of soft drinks and added sugars, particularly high fructose corn syrup, has increased coincident with rising body weights and energy intakes in the population of the United States. Yearly US per capita consumption of nondiet soft drinks rose 86% between 1970 and 1997 alone (22 gal [83.6 L] vs 41 gal).[99] The prevalence of obesity increased 112% during that approximate time.[100] US per capita energy consumption from added sugar rose from 984 kJ (235 kcal) per day in 1977 through 1978 to 1331 kJ (318 kcal) in 1994 through 1996, with soft drinks contributing far more to the total (440 kJ [105 kcal]) than foods such as fruit drinks (130 kJ [31 kcal]) and desserts (251 kJ [60 kcal]).[101]

Although informative, the data just described represent only broad correlations. A true test of links between an environmental agent such as soft drinks and various health outcomes requires a robust literature with studies involving different methods, populations, and outcomes, but most important is a critical mass of studies with strong methods and sufficient sample sizes. These conditions now exist, and several clear conclusions are apparent.

One of the most consistent and powerful findings is the link between soft drink intake and increased energy consumption. Fully 10 of 12 cross-sectional studies, 5 of 5 longitudinal studies, and all 4 of the long-term experimental studies examined showed that energy intake rises when soft drink consumption increases. The effect sizes for these studies, respectively, were 0.13, 0.24, and 0.30.

The available literature also supports the observation that people do not adequately compensate for the added energy they consume in soft drinks with their intake of other foods and consequently increase their intake of sugar and total energy. Noteworthy are findings from several studies that soft drink intake is associated with a higher level of energy consumption than can be accounted for by the soft drinks themselves.[11,17,27,34] These findings raise the possibility that soft drinks increase hunger, decrease satiety, or simply calibrate people to a high level of sweetness that generalizes to preferences in other foods.

Bray et al.[102] noted that the average American older than 2 years consumes 553 kJ

(132 kcal) per day from high fructose corn syrup (the sole sweetener in US soft drinks) and that intake of this sweetener rose 1000% between 1970 and 1990. These authors proposed that fructose is digested, absorbed, and metabolized differently than glucose in ways that favor de novo lipogenesis and do not stimulate insulin secretion or enhance the production of leptin, both afferent signals in the regulation of food intake and body weight.

One would expect a weaker relationship of soft drink consumption with body weight than with energy intake because soft drinks are not the only source of energy in the diet. In addition, higher intake of diet drinks among people with elevated BMIs could reduce or cancel out a relationship between intake of soft drinks overall and body weight. Indeed, cross-sectional and longitudinal studies showed only small positive associations between soft drink consumption and BMI ($rs=0.05$ and 0.09, respectively). More impressive, however, is the fact that a moderate effect size ($r=0.24$) was observed for experimental studies that controlled for many extraneous variables.

In addition to effects on energy intake and weight, it is important to know whether soft drinks displace essential nutrients and contribute to overall poorer diets. Our review showed that increased soft drink intake is related to lower consumption of milk and calcium, but average effect sizes were small. Soft drink consumption was also related to higher intake of carbohydrates, lower intakes of fruit and dietary fiber, and lower intakes of a variety of macronutrients in cross-sectional, longitudinal, and longer-term experimental studies.

Interpreting the association between soft drink consumption and nutrient intake is complex. Soft drink intake could be a marker for poor nutrition, with individuals who consume more sweetened beverages eating poorer diets in general. Soft drinks might also stimulate people's appetite for other nonnutritious foods. One study showed that individuals who consumed more soft drinks consumed diets with higher overall glycemic indexes,[17] supporting the prediction that consumption of foods with high glycemic indexes (such as soft drinks) might stimulate intake of other such foods.[22] Other studies showed that soft drink consumption is positively related to the consumption of foods such as hamburgers and pizza[54] and negatively related to an overall healthy eating index.[16]

A number of studies suggest links between soft drink intake and medical problems. The issues of greatest concern are elevations in blood pressure and increased risk of diabetes. The most striking finding, in a study of 91 249 women followed for 8 years, was that those who consumed 1 or more servings of soft drinks per day (less than the US national average) were at twice the risk of developing diabetes as those who consumed less than 1 serving per month.[17] This result alone warrants serious concern about soft drink intake, particularly in light of the unprecedented rise in type 2 diabetes among children.

Methodological Considerations

There is a great deal of variability in the methods employed in research on the effects of soft drink consumption, and some of these methodological factors have considerable effects on study outcomes. First, we found that effect magnitudes were consistently larger when studies involved more powerful designs (i.e., findings from experimental studies were consistently stronger than those from cross-sectional studies). Second, effect sizes varied significantly depending on other methodological variables such as participant gender, participant age, and beverage type. This heterogeneity not only influences research outcomes but also influences the conclusions that can be drawn from a given study. Different research methods and different definitions of key variables such as body weight further complicate interpretation of findings across studies. Future research with more uniform methodology (ideally experimental designs) would help clarify the impact of soft drink consumption on nutrition and health outcomes.

Industry Funding

The issue of industry funding has been the focus of considerable scrutiny in several areas of medical research, particularly pharmaceutical studies.[103] Our analyses revealed that the overall pattern of results differed significantly when studies funded and not funded by the food industry were compared. As illustrated in Tables 1 through 4, the average overall effect size for industry-funded studies was significantly smaller than the average effect size for nonfunded studies. This discrepancy was particularly striking in studies examining the effects of soft drink consumption on energy intake; effect sizes were moderate ($r=0.23$) for nonfunded studies and essentially nil ($r=0.05$) for funded studies.

Similar results have been reported in other food research. Among studies supportive of the fat substitute olestra, for instance, 80% have been funded by the food industry; by contrast, 21% of neutral studies and 11% of studies critical of olestra have been funded by the industry. In addition, all of the authors disclosing an affiliation with the maker of olestra have published studies supportive of the product.[104]

Conclusions

Available data indicate a clear and consistent association between soft drink consumption and increased energy intake. Given the multiple sources of energy in a typical diet, it is noteworthy that a single source of energy can have such a substantial impact on total energy intake. This finding alone suggests that it would be prudent to recommend population decreases in soft drink consumption. The fact that soft drinks offer energy with little accompanying nutrition, displace other nutrient sources, and are linked to several key health conditions such as diabetes is further impetus to recommend a reduction in soft drink consumption. ■

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