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The impact of water intake on energy intake and weight status: a systematic review

Melissa C. Daniels and **Barry M. Popkin**
Department of Nutrition, School of Public Health, University of North Carolina, Chapel Hill, NC, USA

Abstract

The effects of consuming water with meals rather than drinking no beverage or various other beverages remains under-studied. This systematic review of English language studies compared the effects of drinking water and various beverage alternatives on energy intake and/or weight status. We collected relevant clinical trials, epidemiologic, and intervention studies and summarized findings across the literature. Using clinical trials, average differences in total energy intake at test meals (ΔTEI) were calculated across studies for each of several beverage categories compared to water. The literature for these comparisons is sparse and somewhat inconclusive. One of the most consistent sets of findings comes from comparing adults drinking sugar-sweetened beverages (SSB's) vs. water before a single meal. Total energy intakes were increased 7.8% (ΔTEI range −7.5 to 18.9) when SSBs were consumed. Studies comparing nonnutritive sweeteners with water were also relatively consistent and found no impact on energy intake among adults (ΔTEI = −1.3, range −9 to13.8). Much less conclusive evidence replacing water with milk and juice estimated increases in TEI of 14.9% (range 10.9 to 23.9). These findings, along with epidemiologic and intervention studies suggested a potentially important role for water in reducing energy intakes, and by this means a role in obesity prevention. A need for randomized-controlled trials exists.

Keywords

water; sugar-sweetened beverages; juice; milk; nonnutritive sweetened beverages; energy intake; weight gain

INTRODUCTION

While there is a large and growing literature on the role of a range of beverages on health[1,2], the place of water in supporting health remains under-studied. We are aware of the importance of fluids for survival. Without water humans survive for 2–4 days. Water comprises about 60% of our body weight and is critical for life. Nevertheless we have many unanswered questions about whether consuming water is superior to consuming other fluids or what has been the exact effect of replacing water with other fluids (e.g., various caloric and diet beverages) in our diet. There is an emerging consensus that we do not reduce food intake when we consume caloric beverages[3–5] and there is a need for further exploration of how energy intake and weight status are affected by the selection of various beverages compared to water in the diet. This review explores the hypotheses that 1) choosing

Corresponding author Mailing Address: Barry M. Popkin, Professor of Nutrition, Carolina Population Center, University of North Carolina, 123 W. Franklin St. Chapel Hill, NC 27516-3997, Phone: (919) 966-1732, Fax: 919-966-9159 (backup: 6638), popkin@unc.edu.

alternatives to water at meals (i.e., no beverages, or various caloric and diet beverages) results in differences in energy intake, and 2) that choosing alternatives to water can go beyond affecting energy intake to affecting weight status.

There are a large number of studies and a number of reviews[1, 2, 6, 7] examining the energy intake effects of adding sweetened caloric beverages (SCB's) to our diet, while few studies have examined the effects of fruit juices, milk and other caloric beverages.[8–11] While many of these studies considered water as an alternate beverage, the focus has been on the other fluids. Clearly some of the meta-analyses and reviews have highlighted water as an important comparison group[2] but most have used diet sweeteners or focused on dose responses related to consuming more or less SSB's and other caloric beverages.

The bulk of the literature that relates water to energy intake and weight (by contrasting water with no water or other beverages before a meal) is comprised of short-term clinical studies of energy intake, usually occurring over a 2–5 hour period. There are also a small number of cross-sectional and other epidemiological studies and a few interventions, focused often on energy intake.

METHODS

Literature Search

We performed a systematic review of English language studies evaluating the impact of drinking water compared with no beverage or other beverages on energy intake and/or weight status. Studies were located in a cross-referential manner, beginning with reviews and meta-analyses of beverages and energy intake[1, 12–16] as well as other beverage papers known to us. Reference sections of eligible studies were searched for further relevant studies. Studies citing eligible studies were also evaluated. When titles and subsequently abstracts mentioned beverages, full studies were reviewed for references to water. Reference and citation searches were performed using Web of Science and PubMed. Several short clinical trials, as well as a handful of longer term interventions and observational studies were located.

Inclusion Criteria

Eligible studies evaluated drinking water and one or more of the following comparison beverages: milk, fruit juice, and both diet and non-diet sweetened beverages (i.e., sodas and fruit drinks), or no beverage. These beverages were selected because they are commonly consumed and relevant to population health effects. Criteria and rationales for excluding studies, along with a list of studies fully or partially excluded are detailed in Table 1.

Quantitative and qualitative review

Clinical studies were typically single-blind, preload studies with a cross-over design; most evaluated change in food energy intake at a single meal (usually lunch) served in excess, 0 to 60 minutes after a beverage preload. In 4 studies longer time frames (2 meals to 48 hrs) were available and they are presented and discussed here. Total energy intake (TEI) consumed including preload calories was recorded or calculated for each study, where TEI = (preload kcal + meal kcal). The change in total energy intake (ΔTEI), comparing water against no water or a beverage pre-load was calculated for each study as $\Delta TEI = (TEI_{bev} - TEI_{water}) \div TEI_{water}$. ΔTEI was selected as the main comparative measure because it could be calculated and compared for both caloric and non-caloric beverages, and because total energy intake is directly linked to health effects. In several cases ΔTEI had already been calculated by authors, and calculations were recorded and checked. Relevant statistical comparisons were also recorded. Weighted averages of ΔTEI across multiple studies were

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computed as $\Delta TEI_{wa} = \sum(\Delta TEI*N) \div \sum(N)$. All presented studies were included in weighted averages, regardless of significance. Without individual study data, confidence intervals and P values could not be computed for the weighted averages. Percent compensation (% Comp) has been commonly used elsewhere and is generally defined as the percent of preload calories ($EI_{bev)}$) by which the subsequent meal energy intake (MEI) changed. It was also calculated for all caloric beverages in this study (see appendices A and B) as $\%Comp = ((MEI_{bev} - MEI_{water}) \div EI_{bev})*100$. Where %Comp had already been calculated by authors, calculations were recorded and checked. When specific energy intake data were not listed, requests were sent by email to first and last authors. Six studies were excluded because authors could not be contacted or were unable to provide data.[17–22]

Epidemiologic studies which directly measured the effect of drinking water on energy intake[23–26] or weight status[27–29] were very limited. Two school-based interventions[30,31] and two clinical trials[32,33] of sufficient length to look at the relationship between drinking water weight loss were also located. These studies are summarized and discussed. Energy density studies, or the health impacts of varying the water content of foods and beverages, were not summarized. Total water studies which grouped drinking water intake with food and beverage water were also not summarized.

RESULTS

Clinical, preload, meal studies

A large number of short-term feeding trials compared water with either no beverage or a range of caloric beverages (as shown below). Nearly all used a cross-over design. We examine in order the comparison of water with no water, milk and juices, various caloric sweeteners, and diet beverages. The details of each study are presented in appendices A and B.

Does removing drinking water from meals affect energy intake?

If drinking water is removed from meals, is energy intake affected? We compared six clinical trials that have addressed this. Percent differences in energy intake were summarized in Figure 1 (see also Appendix A).[1]

Among senior adults meal energy intakes increased (ΔTEI_{wa} = 8.7%) when pre-meal water was removed. Three recent studies by Davy and colleagues[33–35] contrasted no water with a water preload 30 minutes before a meal. Meal calories were significantly increased (8.6–14.8%) for both non-obese[35] and overweight/obese[33,34] seniors. Dennis et al. reported one non-significant observation (ΔTEI = 5.4%), however this occurred after a 12 week diet intervention which might have reduced differences at follow-up. No studies looked at time delays other than 30 minutes.

Among non-obese young to middle-age adults (four studies with 9 comparisons) significant changes in energy intake did not coincide with the presence or absence of drinking water (ΔTEI_{wa} = −3.1%). Five comparisons used a 30–60 minute delay (Figure 1, footnote b), whereas four served water with or immediately before meals (Figure 1, footnote w). For all studies, regardless of timing, removing drinking water did not result in significant changes in meal energy intakes (ΔTEI_{wa} = −5.0% water before meals; ΔTEI_{wa} = −1.4% water with meals).

[1]These studies typically presented a reduction in calories when water was added to the diet. In this study we reversed presentation and made water the control to enable comparability with studies of other beverages verses water.

Does substituting water for caloric beverages before or with a meal reduce energy intake?

Water compared to Milk & Juice—How does energy intake change if people drink water instead of juice or milk? Only two adult studies[36, 37] and one study of preschool children[38] addressed this (see Figure 2 and Appendix B). Delay times varied: beverages were served respectively >2hrs before, with the meal, and just before the meal. In adult studies, ΔTEI was significant in 5 of 6 comparisons (range 10.9 to 23.9) and weighted averages appeared similar for both juice (ΔTEI_{wa} =14.4%) and milk (ΔTEI_{wa}=15.2%). The pre-school children reduced their meal intakes by 10% (P<0.01) when drinking milk (juice not tested), but total calories still increased significantly (ΔTEI = 16.7%). Overall, ΔTEI_{wa} was 14.9% for the three studies when individuals drank milk rather than water before or with a meal.

Water compared to Sugar-sweetened beverages (SSB's)—Pre-load studies comparing water intake with SSB's have used various sugars and sugar mixtures. For comparison, studies were organized by the following sugar types: fructose and predominantly fructose (≥65% fructose) beverages, glucose and predominantly glucose beverages, sucrose and high fructose corn syrup (HFCS: usually 55% fructose/45% glucose) beverages. The sucrose and high-fructose corn syrup category contained the largest number of studies, and is shown in Figure 3. Comparisons for glucose and fructose are described.

Water compared to Sucrose and HFCS beverages—Among adults, drinking beverages sweetened with HFCS or sucrose generally raised energy intakes for a single meal compared to water. ΔTEI was positive for 12 of 15 comparisons (ΔTEI_{wa} = 7.8%, range −7.5 to 18.9) and half of these were significant. The four largest comparisons (N>30) all reported statistically significant ΔTEI greater than 8%. [36, 37, 39]

Four studies considered slightly longer time intervals of two or more meals[15,40–42] (See Figure 3, footnote L). All had unique designs elements deviating somewhat from the typical preload paradigm (see appendix B for details). Holt et al.[42] and Lavin et al.[40] considered beverages served with or interspersed with ad lib high fat/high carbohydrate snack foods. One day ΔTEI was not significant for either study (Holt et al. ΔTEI = −7.9%, Lavin et al. ΔTEI = 4.7%), nor were second day intakes recorded by Lavin et al. (1.9%). Mattes et al.[12] and Van Wymelbeke et al.[41] compared intake between two adjacent days. In both studies, total energy intake was significantly higher when a sweetened beverage was served than with water (Mattes et al. cola ΔTEI = 7.2%, P<0.05, water ΔTEI = 1.7%, NS; Van Wymelbeke et al. fruit drink ΔTEI = 24.3%, P<0.05). ΔTEI_{wa} is not presented independently for these four studies due to the variation in study designs. For a single day of intake, combined with the single meal studies above, overall ΔTEI_{wa} was 8.2%.

In the only study of children, Birch et al.[43] compared a sucrose fruit drink to plain water on snack intake in two experiments in pre-schoolers. The children consumed significantly fewer snack calories after a fruit drink compared to water regardless of delay (0, 30 and 60 minutes). Percent compensation was statistically equivalent to 100% in all cases (i.e., children reduced snack calories to perfectly offset their beverage calories). Therefore, TEI (ΔTEI_{wa} =3.1%, significance not tested) is likely to be similar for the two groups.

Time-course effects of semi-liquid preloads on subsequent intake have been previously shown.[44] In response to liquid calories, time course has been hypothesized to be "of central importance[43] although only two studies evaluated multiple delay times.[43, 45] Therefore we evaluated for adult single meal HFCS and sucrose studies whether time delay from preload to meal had an influence on ΔTEI. When beverages were served with meals (6 comparisons, Figure 3, footnote w) most comparisons were clearly positive and significant (ΔTEI_{wa} = 10.0%, 4 of 6 significant comparisons, with one (ΔTEI = 9.9) not tested). In contrast, when adult subjects drank a sucrose or HFCS beverage (vs. water) 30 minutes or more *before* a meal (9 comparisons, see Figure 3, footnote b) ΔTEIs varied greatly (range=−7.5 to 18.9) but were not generally significant (ΔTEI_{wa}=5.5%, 2 of 9 significant, with one (ΔTEI=0.0) not tested). The comparison by Almiron-Roig et al.[36] is a clear outlier as their preload was 135 minutes prior to the test meal (all other studies were between 30 and 80 minutes – see appendix B for listed delay times). When this study is excluded, ΔTEI_{wa} drops to 1.6% (range = −7.5 to 12.5) for the remaining 8 studies with only one study significant.

Water compared to Glucose and Fructose sweetened beverages—Few studies have compared glucose or fructose sweetened beverages and water (see Appendix B). Four compared a glucose beverage with water[46–49] and one used an 80/20 glucose/fructose blend.[50] All preloads were served at least 30 minutes before meals. Results were inconsistent and ranged widely (ΔTEI_{wa} = 19.3%, range = −10.2%, 45.3%). Fructose beverages and water were compared five times in four studies[46, 48, 49, 51] and one study compared 20/80 and 35/65 glucose/fructose blends.[50] All preloads were served at least 30 minutes before meals. ΔTEI was positive in 5 of 7 cases (ΔTEI_{wa} = 4.5%) but never significant, and the range of differences was again wide (−7.9% to 25.1%). Overall, the wide ranges and limited data for glucose and fructose made it difficult to discern any trends.

Does drinking water, compared to diet beverages, before or with a meal impact energy intake?

Studies containing diet beverages typically used aspartame or beverages generally sweetened with aspartame (diet Coke and diet Pepsi); two comparisons with saccharin,[47, 52] and one with acesulfame-K[47] were also included, as well as a study which combined all three sweeteners in one beverage.[41]

Ten adult studies gave a total of 19 comparisons. Sixteen comparisons reflected intakes at single meals. Differences were distributed on either side of zero (ΔTEI ranged from −7.4 to 6.1%; ΔTEI_{wa} = −1.4%) and all differences were non-significant. Three longer studies (2+ meals previously discussed) also looked at diet beverages. Differences in TEI were non-significant, except in the one 2-day comparison. Lavin et al. (1997) reported a non-significant ΔTEI of 7.6% at the end of dinner when women drank diet lemonade, but by day 2 ΔTEI had increased to 13.8% and was significant ($P<0.05$).

Birch et al.[43] (see above description and Appendix B) again provided the only study in children. Young children consumed significantly fewer snack calories when diet fruit drinks compared to water were served 30 minutes before the snack, but not with a longer delay (60 min) or no delay. This pattern was repeated in a second similar experiment. Across all comparisons, ΔTEI_{wa} was −6.7%.

EPIDEMIOLOGICAL AND INTERVENTION STUDIES

Epidemiological population-level impacts of drinking water on energy intake

Four recent US studies (see Table 2) have explored the population-level benefits of drinking water on energy intake. Three used water data from the US National Health and Nutrition Examination Survey (NHANES) to conduct cross-sectional analyses. Two used fixed effects modeling, which uses individuals as their own controls and may reduce confounding by other variables.

Two of the NHANES studies and one of the fixed effects studies focused on adults. Popkin et al.[23] reported healthier dietary patterns including reduced soda intake and lower energy intakes among water drinkers in the 1999–2001 NHANES. Kant et al.[26] (1999–2006 NHANES) found that energy intake could not predict plain water intake, but was positively

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associated with consumption of other beverages. Stookey et al.,25 using a fixed effects longitudinal model, evaluated women's weight and water intake changes over 12 months and found reduced energy intakes when women replaced other beverages with water. For each 1% reduction in beverages due to replacement with water, energy intakes were reduced −9kcal (SSBs), −8 kcal (milk, juice, or alcohol), and −3 kcal (non-caloric beverages). When all sweetened-caloric beverages were replaced with water, energy intakes were reduced by 200kcal/day. No benefit was predicted if sweetened-caloric beverages were replaced by other caloric beverages.

Wang et al.24 considered water intake in children (ages 2–19y) using a fixed-effects model over two days of intake. For each 8oz serving of a range of beverages, energy intakes increased commensurate with beverage calories [no change (water and diet beverages) P>0.20; 106 kcal (SSB's), 169 kcal (whole milk), 145 kcal (reduced fat milk) and 123 kcal (juice); P <0.001 for all caloric beverages]. Overall, authors estimated a reduction of 235 kcal/day if all SSB's were replaced with water.

Epidemiologic studies of water and weight status

Epidemiologic studies exploring the relationship between drinking water and weight status (see Table 3) were limited to two GLM analyses controlled for body size, and one more complex mixed models analysis (individuals were their own controls).

Two studies focused on adults. Phelan et al.28 used simple GLM models to compare diets of weight-loss maintainers and normal weight controls from the national weight control registry. Weight loss maintainers drank more water servings (4.7 vs. 3.5, P=0.002), with larger portions (2.03 servings vs. 1.35 servings, P = 0.0001). Stookey et al.,29 using nested mixed models, found greater losses in weight (2.3kg) and waist circumference (2.3cm) when individuals drank >1L water/day over 12 months. Replacing 1% of sweetened beverage intake with water also significantly reduced weight (0.03 kg [P<0.05)], waist circumference (0.03 cm (P<0.05), and body fat (0.02%, P<0.05).

In the only child study, Johnson et al.27 compared fat mass (at age 9y) with previous beverage data (5 and 7y). Neither earlier water nor SSB intake predicted fat mass by age 9y. However, authors admitted low energy intakes (~30% implausible) with under-reporting substantial among overweight children. Low reported consumption of SSB's in this sample (~150 to 300 g/d or 5–10 oz/d) and even lower water intakes (~100 to 150 g/d or ~3.5–5oz/d) are questionable.

Intervention studies of water and weight status

Only four studies exploring water drinking as a weight loss intervention were located (see Table 3). Two were clinical studies of older adults based at Virginia Tech, US; two were school-based interventions in English and German Primary Schools.

The two clinical studies performed weight loss interventions on older adults and seniors. In addition to weight loss training, a portion of the sample was assigned to drink water before meals. Dennis et al.33 observed a significant decrease in total fat mass at 12 weeks among water drinkers (−5.4±0.6kg vs. −3.3±0.5kg, P=0.01), although reductions were not significant when expressed as % of initial weight, or % body fat. BMI and Waist circumference were not significantly different. Davy et al.32 (reporting preliminary results of a 6 month intervention) observed a tendency to greater weight loss (−11kg vs. −7kg, P = 0.09). Both studies reported more rapid weight loss among pre-meal water drinkers.

James et al.30 delivered an educational intervention to 15 classes in 6 schools (14 control classrooms had no intervention) to reduce consumption of carbonated beverages and increase water drinking. Four 1-hour classes (by one investigator) presented a variety of instruction, demonstrations, music, contests and games. At one year, children completed two 3-day drink diaries. Intervention classes reported lower carbonated beverage intake [difference=0.7 glasses/3days (0.1 to 1.3)] and children were weight stable (change in % overweight −0.2% vs. +7.5% controls). Reported water intakes increased similarly for both groups, however, authors reported a low return rate for the two diaries (55% initial, 56% final, 36% both).

Mucklebauer et al.31 instituted both educational and environmental interventions to increase water intake in 17 German schools (15 control schools had no intervention). Teachers presented four empirically developed lessons about the body's water needs and the water cycle. Special filtered drinking fountains were installed, water bottles distributed, and teachers were encouraged to organize filling of water bottles each morning. After one year children completed 24-hr beverage intake recalls in class. Interventions schools had higher water intakes (1.1 glasses/day, P<0.001), and lower adjusted risk of overweight (OR = 0.69, 95% CI 0.48–0.98).

CONCLUSION

This review clarifies what is known about the effects of drinking water on energy intake and weight status, as well as highlighting critical literature gaps. The review does not support that removing drinking water from a meal significantly changes TEI, although a small increase in TEI was seen in older adults. In contrast, for adults, the review finds reasonable agreement among a number of single meal studies that replacing water with sugar-sweetened beverages will increase energy intake (7.8% ΔTEI_{wa}, range −7.5 to 18.9). There were far fewer studies replacing water with juice and milk but the weighted average showed a sizeable increase in total energy intake (15% ΔTEI_{wa}, range 10.9–19.7). The literature on comparison of water with artificially sweetened beverages found a negligible statistically insignificant reduction in energy intake (−1.4% ΔTEI_{wa}, range −9.0 to 13.8%).

The review highlighted a number of key gaps in the caloric beverage literature. Studies comparing water with caloric beverages in children were almost non-existent. The single existing study in children found no difference in TEI when kids consumed SSB's (3.1%, NS), contrasting sharply with the increase reported when kids drank milk (16.7%). The largest set of studies relates SSB's and water intakes at single meals in adults. Results from HFCS and sucrose were much more conclusive with a 7.8% increase in total energy and many studies statistically significant. We did find great heterogeneity in adult studies and findings based on sweetener type with a range of studies on HFCS and sucrose and minimal work on beverages sweetened with pure fructose or glucose. Very few studies considered energy effects of water vs. other beverages at more than one meal, and these had increasingly divergent study designs and findings. Clearly, all of this literature is very short-term and the critical gap is longer-term randomized controlled trials.

The diet sweetener literature is not very conclusive. Elsewhere we recently reviewed what is known about consumption patterns and biological pathways by which these sweeteners might affect behavior.53 Diet beverages have been compared frequently to various solid and liquid preloads,13 but less commonly with plain water. In this review artificially sweetened beverages clearly did not increase energy intake at the next meal compared to plain water. Again, very few studies have considered effects longer than one meal.

Dietary regulation may differ by age; unfortunately most studies explored regulation only in adults and very few contrasted different ages. The study of children by Birch found greater ability to compensate for beverage calories than the collection of adult studies (Figure 3).

The studies of seniors by Davy and colleagues (Figure 1), found a tendency to reduce caloric intake when water was consumed before a meal; while studies of younger adults found no clear effect. With just a few studies on children, it is almost impossible to provide any sense about dietary regulation as it relates to beverages and water in children. Research is needed to explore age effects, and clarify age brackets where regulation may vary.

This review suggests delay time may impact the effect of caloric beverages on energy intake. When adult single meal SSB studies were stratified by delay time, ΔTEI_{wa} was 1.6% with all but one study non-significant if beverages were served 30–80 minutes before meal. ΔTEI_{wa} was 10.0% and generally significant if served with a meal. Juice and milk studies had a larger ΔTEI_{wa} (14.9%) but all served beverages with or long before meals (2+hrs), which appeared to increase TEI relative to short delays in SSB studies. As hypothesized by Birch 20 years ago, time course may indeed be "of central importance"[43] in modulating the effect of liquid calories on energy intake and appears worthy of attention in future studies.

The epidemiologic literature exploring the effects of water on energy intake and weight status is also strikingly sparse and this along with variation in study designs made drawing broad conclusions difficult and we must be cautious in our interpretation. In general studies supported an inverse relationship between drinking water and energy intake when compared with other beverages[23–25] with both fixed effects studies estimating a reduction of 200+ kcal per day if all sweetened caloric beverages were replaced with water.[24,25] The adult studies by Phelan et al.[28] and Stookey et al.[29] looking at weight status supported an inverse relationship with water drinking, while the study by Johnson et al.[27] did not, but was focused on children and suffered from substantial underreporting. Of the epidemiologic studies, the two Stookey papers were most noteworthy, both for their careful modeling with fixed effects and because they were secondary analyses of intervention data (rather than observational). By following women on a range of diet plans that shifted water intake, the studies found significant differences in energy, weight and % body fat among the higher water drinkers.[54,55]

While further epidemiologic studies would be desirable, there are challenges to this literature. With self-reported dietary data (used in all of the above studies) underreporting is common and is thought to occur similarly with both water and energy intakes.[56] Since underreporting for water and energy intakes is thought to be balanced, whereas dietary underreporting is known to differ by weight, the studies of weight status naturally require a more cautious interpretation. Another notable challenge for epidemiologic studies is isolating the effects of water drinking. The studies by Popkin et al.[23] and Kant et al.[26] agree with other studies[57] that water intakes are strongly tied to other dietary patterns. Both studies also demonstrate the known coexistence between dietary pattern differences and socio-demographic differences. Since the two are so tightly linked, removing socio-demographic variation to control confounding also limits diet pattern variation, and may obscure related water benefits. Does drinking water support other more healthful dietary patterns? Or does it merely coexist with them? Clearly further studies are needed to answer this question.

Few intervention studies rigorously examined the role of water education or using water to replace other beverages consumed at the school. The most potentially intriguing result was the German intervention in 32 schools. This year-long German intervention promoted water both by educating about the importance of water and making filtered water readily available to children. The intervention schools increased water intake 220 ml/d with a significant 31% reduction in the risk of overweight.[31]

This review suggests plausible benefits from increasing water intake and invites further investigation. Reduced energy intakes are expected when water replaces other caloric beverages at a single meal, but this may not translate into long-term weight changes. For example, drinking milk and SSBs both increased single meal energy intakes substantially compared to water, but Stookey et al.[29] and Johnson et al.[27] both found that milk was much less likely than SSBs to promote weight gain. Longer-term random controlled trials of water drinking and weight status are needed to understand these relationships.

Limitations in this review really relate to the lack of randomized controlled trials and more studies that go beyond short-term feeding trials to week, month and longer studies. Most of the studies in this review looked at energy intakes at a single meal following a beverage preload, and very few examined the effects of water drinking on more than a day or two and certainly not on 3–6 month or even a year changes in energy intake or weight. It is critical to understand that future designs should include some randomized controlled trials of the effects of replacing SSB's, other caloric beverages and diet beverages with water. Since there are sociodemographic characteristics, this will be important for fully understanding the future program and policy agenda most clearly.

Along with the great deal of further research to needed to define the relationship of water drinking and weight status, research is needed to understand the driving mechanisms supporting these relationships. Rather than assuming energy intakes are the only way water intake may affect weight, some early studies support the presence of alternate metabolic pathways. Boschmann has shown increased thermogenesis and caloric expenditure within 60 minutes of drinking water.[58, 59] Others have suggested that reduced serum osmolality from drinking water may improve cell efficiency and increase fat metabolism.[60, 61] Unfortunately, existing research toward these theories is at present very limited, and at best, speculative, and much more work is needed.

Obesity is clearly linked to a host of health problems, and this connection alone supports promotion of water drinking. Outside of this the unique benefits of water drinking are less well defined. Clearly maintaining adequate hydrational status has important health implications – this is discussed at length in a companion paper.[62] Most beverages can support hydration, but water is unique in doing this without also adding sugars or many other compounds into the diet. Unfortunately, little research exists exploring the broader health implications of this; however, recent studies linking SSBs to increased rates of diabetes[63] and heart disease[64] through pathways independent of BMI begin to imply even further benefits of water drinking.[65–68] We do not review this sparse literature as there is little consensus yet on any of these alternate pathways.

Very recently the American Heart Association published a statement that raised significant questions about the high level of added sugar in the US diet and suggested that American women should consume no more than 100 calories per day while American men should consume no more than 150 calories per day from added sugars.[69] Given the very high intake of calories from beverages in the US diet, this would necessitate major shifts in the beverage patterns of Americans.[70, 71]

This review examined a potentially important replacement beverage. Overall this review suggests promising results for promoting water. As we have shown elsewhere, the proportion of water in our diet has diminished over time as we have shifted to a range of beverages that contain either one or many of the following: sugar, caffeine, natural and artificial flavorings, nonnutritive sweeteners, and carbonation. The beverage revolution in the post WWII period has truly shifted our ways of drinking and possibly even our total fluid intake.[5, 70–72] What we need to understand and still do not is: "will we benefit by shifting back to water more than to other beverage options that reduce or eliminate calories from our diet?" Longer-term randomized controlled trials and more interventions with strong compliance monitoring designs are needed to fully understand the benefits of water replacing both a range of caloric and nonnutritive beverages.

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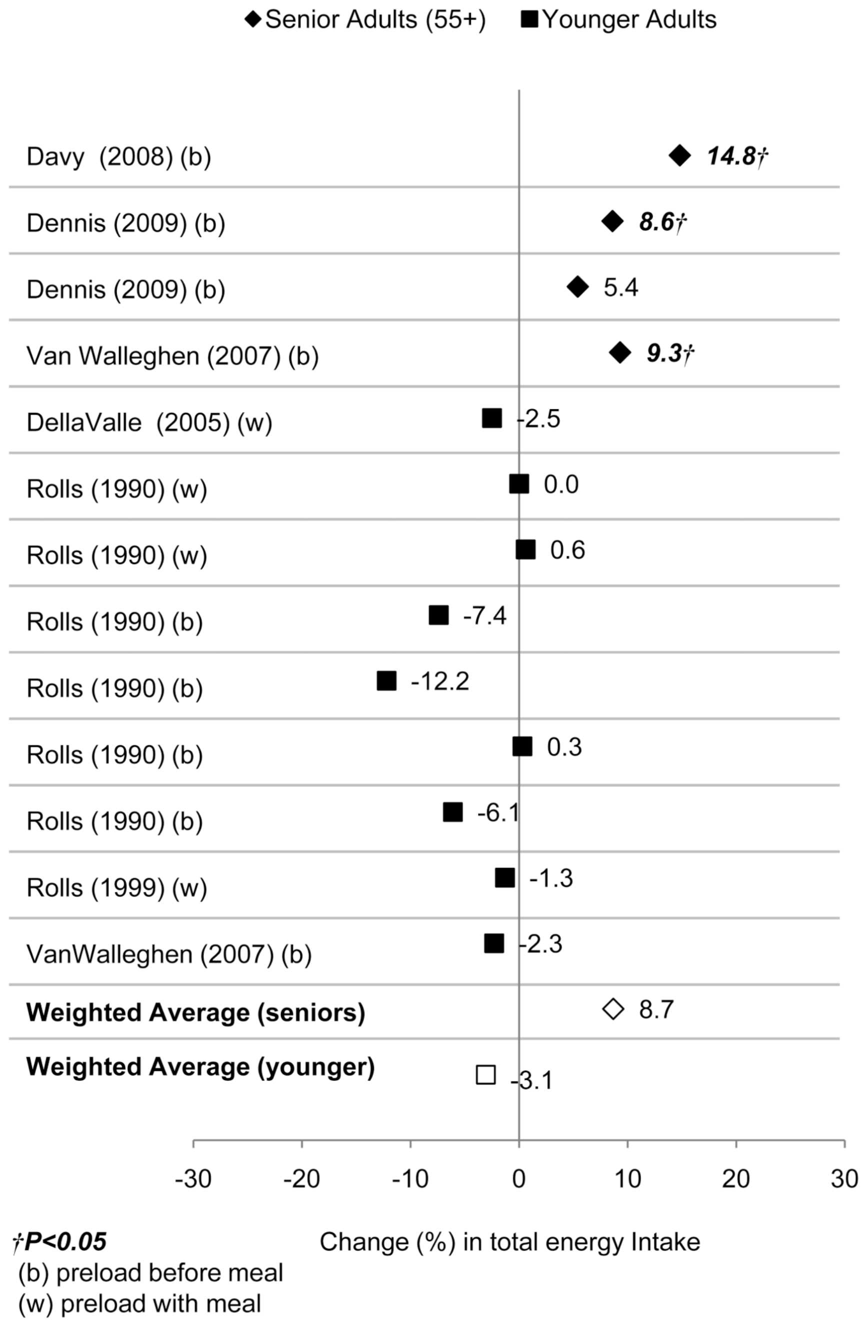

Figure 1. Difference in total energy intake when drinking water is removed from a meal
Total energy intake (TEI) includes combined kcal from preload and test meal. Differences presented are %ΔTEI calculated as 100*(TEI(w/no water)−TEI(w/water)) / TEI(w/water). Weighted averages of ΔTEI across multiple studies were computed as $\Delta TEI_{wa}=\sum(\Delta TEI*N) \div \sum(N)$. All presented studies were included in weighted averages, regardless of significance.

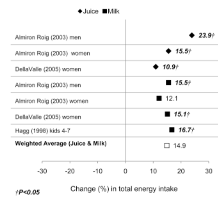

Figure 2. Difference in total energy intake when juice or milk displace water

Total energy intake (TEI) includes combined kcal from preload and test meal. Differences presented are %ΔTEI calculated as 100*(TEI(w/beverage)−TEI(w/water)) / TEI(w/water). Weighted averages of ΔTEI across multiple studies were computed as $\Delta TEI_{wa} = \sum(\Delta TEI * N) \div \sum(N)$. All presented studies were included in weighted averages, regardless of significance.

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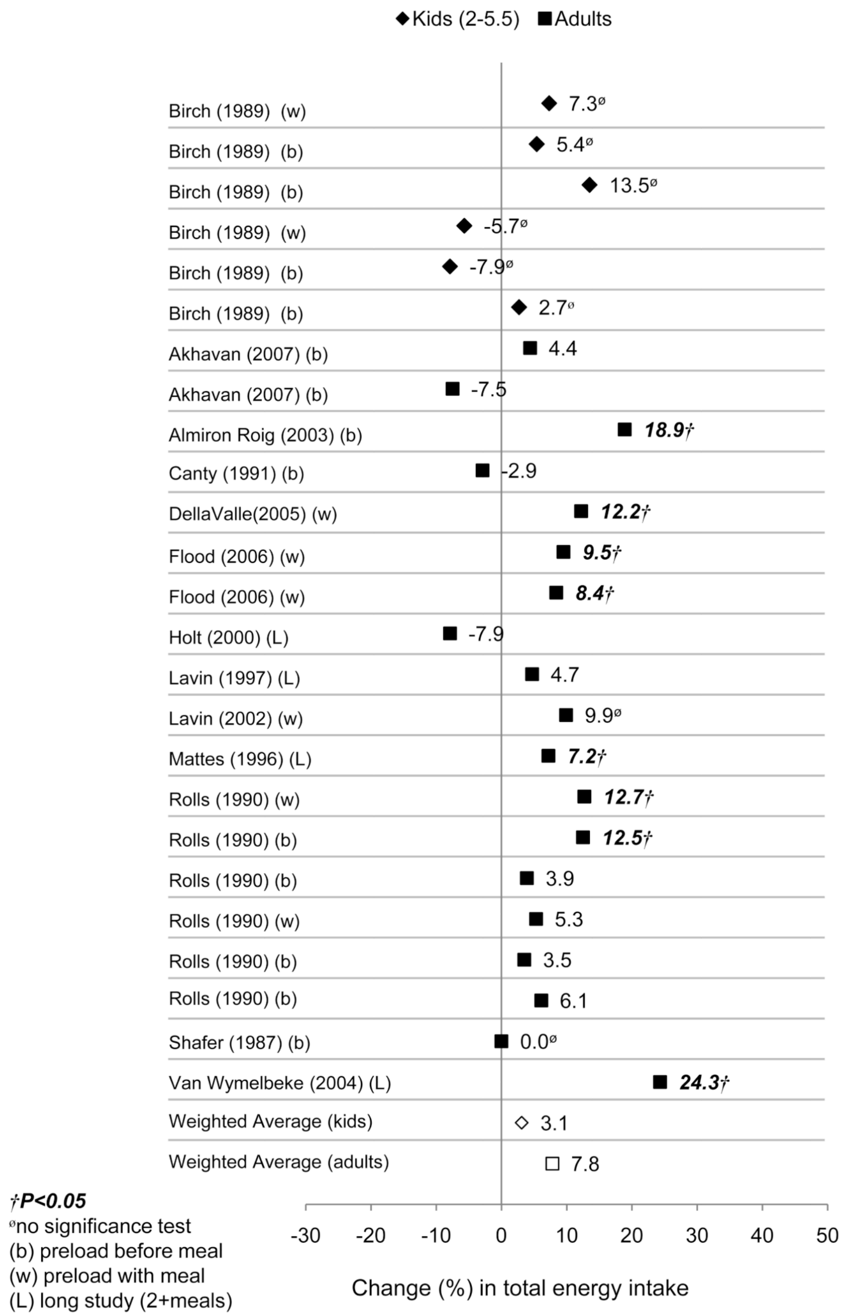

Figure 3. Differences in total energy intake when HFCS or sucrose sweetened beverages displace water

Total energy intake (TEI) includes combined kcal from preload and test meal. Differences presented are %ΔTEI calculated as 100*(TEI(w/beverage)−TEI(w/water)) / TEI(w/water). Weighted averages of ΔTEI across multiple studies were computed as $\Delta TEI_{wa} = \sum(\Delta TEI * N) \div \sum(N)$. All presented studies were included in weighted averages, regardless of significance.

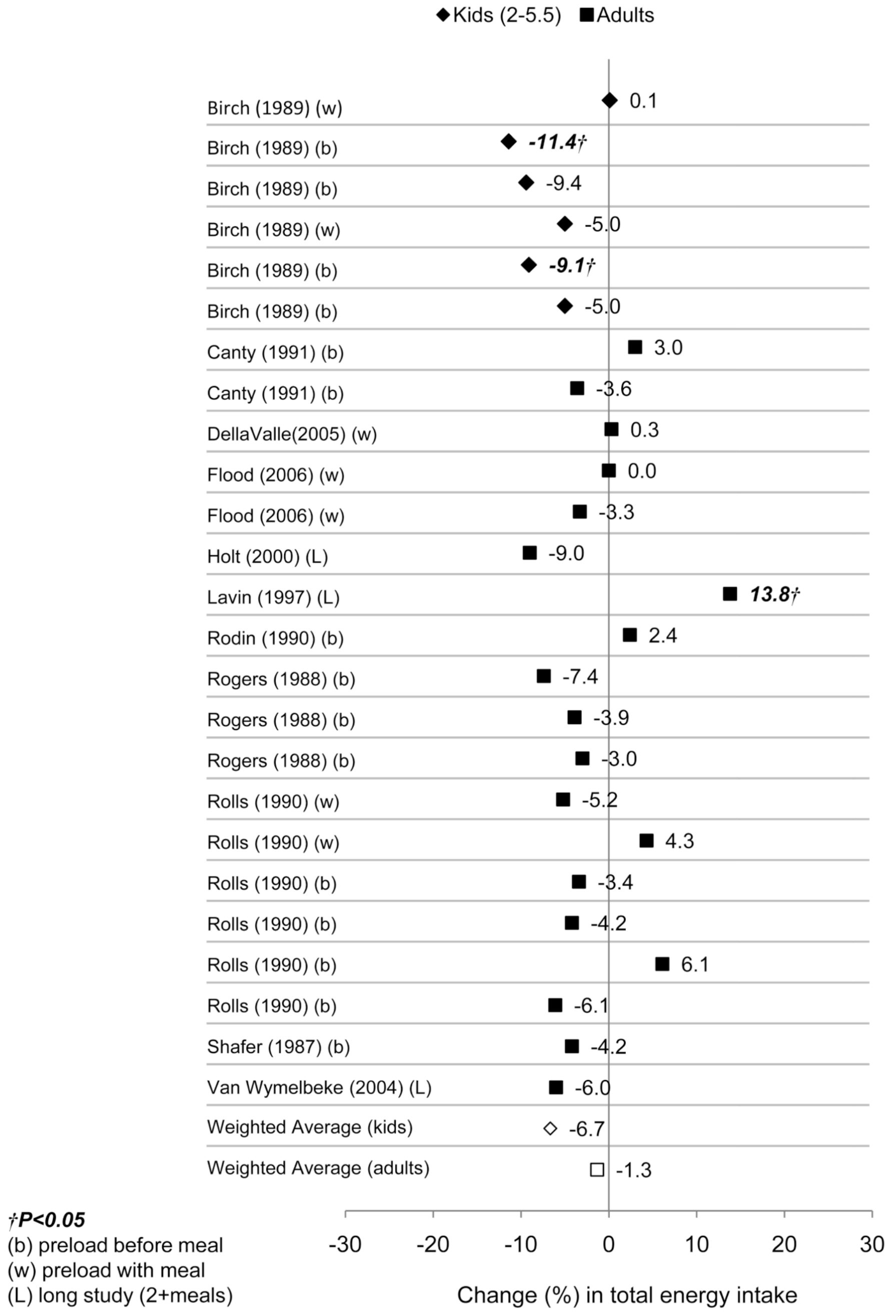

Figure 4. Differences in total energy intake when diet beverages displace water

Total energy intake (TEI) includes combined kcal from preload and test meal. Differences presented are %ΔTEI calculated as 100*(TEI(w/beverage)−TEI(w/water)) / TEI(w/water). Weighted averages of ΔTEI across multiple studies were computed as $\Delta TEI_{wa}=\sum(\Delta TEI*N) \div \sum(N)$. All presented studies were included in weighted averages, regardless of significance.

Table 1

Criteria and rationale for exclusions, and list of excluded studies

Exclusion Criteria	Rationale for exclusions	Studies fully or partially excluded
Non-conventional beverages enriched with proteins and fats	Limited availability; Limited usage	Westerterp-Plantenga and Verwegen 199921; Wilson et al. 200222; Woodend and Anderson 200173.
Comparison beverages with sugars and sugar mixtures other than sucrose, fructose, glucose	Limited availability; Limited usage	Birch et al. 198943; Raynor and Epstein 200020; Shafer et al. 198748; Yeomans et al. 199974.
Beverages with mixed caloric and non-caloric sweeteners	Unable to be grouped cleanly with caloric and non-caloric beverages	Woodend and Anderson 200173; Akhavan and Anderson 200750; Birch et al. 198943; Guss et al. 199451; Spitzer and Rodin 198749.
Comparisons with alcoholic beverages	Previously shown to be additive to meal calories75; unclear relationship between alcohol calories and BMI appears to rest on absorption and metabolism issues unable to be addressed.	Mattes 199612; Poppitt et al. 199676; Westerterp-Plantenga and Verwegen 199921; Yeomans et al. 199974; Yeomans and Phillips 200277.
Studies presenting a food item that varied with the preload	Masking of beverage effects	Cecil et al. 200578.
Studies of athletes, studies in conjunction with exercise, military studies.	Representation of extreme circumstance not necessarily relevant to typical physiologic process.	Engell 198879; Engell D 199580; King et al. 199981.

Table 2

Epidemiologic studies of water intake influencing energy intake

First author (year)	Funding (I,N,M)	Sample characteristics (N gender, age, BMI)	Study name location & time	Study design	Duration	Outcome	Related findings
Kant (2009)26	N	12,283 M&F, >20y, mw 4112 M&F, >20y, mw	1999–2004 NHANES (US, nationally representative) 2005–2006 NHANES	Cross-sectional linear model estimating water intakes (plain, beverage, and total waters) as a function of energy intake and other dietary factors. Analysis was conducted separately for each dataset.	NA	Plain water intake was not significantly predicted by energy intake in either dataset.[1]	Plain water drinking was inversely related to consuming other beverages (−14.5g beverage water/ 100 g plain water, P<0.0001). Other beverages were positively associated with energy intake (44.1 g beverage water / 100 kcal, P<0.0001).
Popkin (2005)23	I	4755M&F, >18y, mw	1999–2001 NHANES	Cross-sectional; Cluster analysis evaluating food and energy intake patterns of water drinkers (87%) compared to those who did not drink water.	NA	Water consumers drank on average 1.5L of water and consumed 194 fewer kcal per day.[2]	Water drinkers had healthier eating patterns including fewer kcal per day from sodas (−137), fruit drinks (−15) and fast foods (−62).
Stookey (2007)25	I	118F, 25–50y, 27–40 kg m^{-2}	Stanford A to Z weight loss trials, California, ~2005–2006	Longitudinal; Fixed effects study comparing impact of various diet plans on weight loss and fat loss. Modeled changes in beverage intake and energy intake among baseline sugar-sweetened beverage (SSB) consumers.	1 Year	Replacing all SSBs with water, predicted mean energy intakes were decreased by 200kcal/day over 12 months.[3]	Replacing SSBs with non-caloric beverages, decreases were smaller; Replacing SSBs with nutritious caloric beverages did not reduce energy intake
Wang (2009)24	N	3098 kids, 2-19y, mw	2003–04 NHANES	Cross-sectional; Fixed effects analysis of two 24-hr recalls estimating the impact on total energy intake (TEI) of replacing sugar-sweetened beverages (SSBs) with healthier alternatives.	NA	Replacing all SSBs with water could reduce kid's TEI on average 235 kcal/day.[4]	Total Energy Intake increased >100 kcal per 8oz (237mL) serving of milk, juice and soda, but did not increase with water or diet beverages.

Abbreviations: I=Industry, N=Non-industry, M=mixed industry and non-industry. mw=mixed weight (normal, overweight and obese); NHANES: US National Health and Nutrition Examination Survey;

[1] Plain water category excluded unflavored carbonated water. Model controlled for sex, age, race-ethnicity, body mass index, poverty-income ratio, years of education, smoking status, day of diet recall, leisure-time physical activity, average daily physical activity, any self-reported chronic disease, and survey wave.

[2] Water category included tap or plain spring water. Unflavored carbonated water not mentioned.

[3] Model controlled for total beverage intake, non-caloric and nutritious caloric beverages, food composition and energy expenditure.

[4] Model controlled for changes in other beverage consumption, day of the week, fast-food intake, and non-beverage intake. Using two time points, Individuals were their own controls.

Table 3

Intervention and epidemiologic studies of water intake influencing weight status

First author (year)	Funding (I,N,M)	Sample characteristics (N gender, age BMI)	Study name location & time	Study design	Duration	Outcome	Related findings
Epidemologic studies							
Kant (2009)26	See Table 2 above. Unadjusted plain water intakes did not vary by weight status in 2005–2006 NHANES; Plain water intakes were higher among those with higher BMI in 1999–2004 NHANES analysis.						
Johnson (2007)27	N	Round 1: 521 kids, 5.2±0.6y, 16.0±1.4 Round 2: 682 kids, 7.4±0.1y, 16.2±2.1 Round 3: 692 kids, 9.8±0.2y, 17.7±2.8	ALSPAC; England; ~1997–2001	Longitudinal study; GLM model of fat mass at age 9y as a function of beverage consumption at ages 5 and 7y.[a] Water category included flavored water.	4 years	Water intake at age 5 and 7y was not significantly associated with change in fat mass by age 9y in crude or adjusted models.	SSB intake did not predict fat mass by 9y. Higher milk intake significantly predicted lower fat mass (at 5y, -0.51kg/serving P<0.01; at 7y -0.35kg/serving P<0.01)
Phelan (2009)28	M	131M&F, 49.9±13.2y, 21.3 kg m^{-2} (always NW) 172M&F, 48.2±11.6, 22.0 kg m^{-2} (WLM)	Sample from National Weight Control Registry (US). Study dates not specified.	Cross-sectional study using three 24hr recalls. Simple GLM comparison of food and beverage intakes of normal weight individuals with weight loss maintainers.	NA	Water was main beverage for both groups; WLM drank more daily servings of water (4.7 vs. 3.5; P=0.002).	WLM also had larger serving sizes for water (P=0.0001); and marginally greater % of overall beverage intake from water (P=0.06).
Stookey (2008)29	M	173F, 25–50y, 27-40 kg m^{-2}	Stanford A to Z California, ~2005–2006	Longitudinal study over 12 month; Used nested mixed models to estimate effects of absolute and relative changes in water intake on weight gain. Participants from four diet groups.	1 year	Individuals drinking >1L water/day lost on average 2.3kg more weight and 2.3cm WC than those drinking <1L/day[b]	Replacing 1% of SSBs with water significantly reduced weight (0.3kg), WC (0.03cm) and body fat (0.03%).
Intervention studies							
Davy (2008)32 (abstract only)	NL	29M&F, 62±1y, 33±1kg m^{-2}	Virginia Tech; 2006 - present	Clinical Intervention study comparing drinking water before meals vs. control; groups received identical weight loss intervention.	6 months	Mean wt loss: −11±2kg (water) −7±1kg (control) P=0.09 (Still in progress: 20 of 29 had completed 6 months.)	Rapid weight loss was more common and more often sustained among pre-meal water drinkers.
Dennis (2009)33	N	18M&30F, 55–75y, 25–40 kg m^{-2}	Virginia Tech; Jul06-Sep08	Clinical Intervention study looking at the difference in weight loss when a low-	12 weeks	Significant weight loss in both groups; greater weight loss	Differences in %wt, % body fat, BMI, waist

First author (year)	Funding (I,N,M)	Sample characteristics (N gender, age BMI)	Study name location & time	Study design	Duration	Outcome	Related findings
				calorie diet is coupled with pre-meal water (500 mL) or no water instructions.		rate in water group. Water consumers had significantly reduced fat mass (P=0.01).	circumference, blood pressure and blood lipids were not significant.
James (2004)30	M	324boys &320girls, 7–11y, MW	CHOPPS; Southwest England; Aug 01-Oct 02	Primary school class-room level intervention to reduce carbonated drinks and increase water drinking. Various educational methods used: didactics, slogans, games, contests, music.	1 school year	Percent overweight increased significantly for controls (+7.5%) but not intervention (−0.2%) group.	Increases in water intake were similar for both groups, while SSBs decreased with intervention. Substantial underreporting.
Muckelbauer (2009)31	N	2950 kids, 8.3±0.7y, MW	Germany; Aug 06-Jun 07	Primary school school-level intervention to promote drinking water and reduce overweight. Intervention was both educational (didactic) and environmental (filtered fountains, water bottles, daily filling process).	1 school year	Intervention group water intake was 220mL/day greater; Adjusted risk of overweight was 31% lower for intervention group. [OR=0.69 (95% CI 0.06, 1.91)]	Intervention had no effect on soft drink and juice consumption.

Abbreviations: I=Industry, N=Non-industry, M=mixed industry and non-industry. MW=mixed weight (normal, overweight and obese); NW=normal weight; WLM=weight loss maintainers; WC=waist circumference; SSBs=sugar-sweetened beverages; CHOPPS: Christchurch Obesity Prevention Projects in Schools; ALSPAC: Avon Longitudinal Study of Parents and Children; CHNS: Chinese Health and Nutrition Survey.

[a]Model was adjusted for sex, height at 9 y, child's body mass index at baseline, television watching, maternal education, paternal class, maternal body mass index, paternal body mass index, misreporting of energy intake (energy intake per estimated energy requirement), dietary energy density, percentage of energy intake from fat, and fiber density.

[b]Model was adjusted for age, race/ethnicity, baseline status, and diet treatment group, energy expenditure, energy intake from food, and food macronutrient and water composition.

[c]Defined as mean percentage >91st centile.

Appendix A

Clinical trials of energy intake in the absence and presence of drinking water

First author (year)	Funding (I,N,M)	Sample characteristics (N gender, age, wt)	Trial type; test meal(s)	Time delay[a] (min)	Beverage preload (mL)	Meal intakes Kcal±SEM	% ΔTEI[b]	P value
Davy et al. (2008)32	N	7M & 17F, 55–75y, ow/obese	CO2; B[β]	30 min	water (500) no water	500±32 574±38	control 14.8	0.004
DellaValle et al. (2005)[c]37	N	44F, 18–60y, mw	CO6[‡]; L	w/meal	water (360) no water	790±34 770±41	control −2.5	NS
Dennis et al. (2009)33	N	18M&30F, 55–75y, ow/obese	CO2, B[β]	30 min *At 12 weeks*[d] 30 min	water (500) no water *At 12 weeks*[d] water (500) no water	498 ± 25 541 ± 27 480 ± 25 506 ± 25	control 8.6 control 5.4	0.009 0.069
Rolls et al. (1990)45	N	14M, 21–39y, nw 14M, 21–39y, nw 14M, 21–39y, nw	RCT/CO7[‡], L[ψ] (3 experiments; groups differed only by time delay)	w/meal 30 min 60 min	water (237) no water water (473) no water water (237) no water water (473) no water water (237) no water water (473) no water	1083±90 1083±67 1077±88 1083±67 1137±148 1053±110 1199±160 1053±110 1147±73 1150±47 1225±67 1150±47	control 0.0 control 0.6 control −7.4 control −12.2 control 0.3 control −6.1	NS NS NS NS NS NS
Rolls et al. (1999)82	N	24F, 20–45y, nw	CO4; L[ψ], D[ψ]	5 min	water (356) no water (with casserole)	396±35 391±35	control −1.3	NS
Van Walleghen et al. (2007)35	N	14M & 15F, 21–35y, non-obese 11M & 10F, 60–80y, non-obese	CO2; L[ψ]	30 min	(500 M, 375F) water no water water no water	913±54 892±51 624±56 682±53	control −2.3 (young) control 9.3 (seniors)	NS 0.02

Abbreviations: I=industry, Non-industry, M=mixed, M/F=male/female, nw=normal weight , ow=overweight, mw=mixed weight, CO#=crossover and # of repeated experiments, B=Breakfast, L=Lunch, D=Dinner, NC=not calculable, NS=not significantly different (P>0.05).

[‡] See Table 3 below for other beverages also evaluated.

[β] test meal included caloric beverages

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[ψ] test meal included water

[a] Time delay = minutes from preload to test meal(s)

[b] Total energy intake includes combined kcal from preload and test meal. %ΔTEI is calculated as 100*(TEI(w/no water)–TEI(w/water)) / TEI(w/water). “With water” is designated as the control in all cases for comparability with beverage studies (see Appendix B).

[c] Additional data was supplied by author(s).

[d] 12-week intervention included low-calorie diet combined with pre-meal water intake (500mL), or diet with no water intake.

Appendix B

Clinical trials of energy intake in the presence of beverages or water

First author (year) (experiment)	Funding (I,N,M)	Sample characteristics (N gender, age, wt)	Trial Type; Test Meal(s); Notes	Time Delay[a] (min)	Beverages (sweetener) (mL)	Bev. Energy (kcal)	Meal Intakes Kcal±SEM[b]	% ΔTEI [c]	P value[d]	% Comp
Akhavan & Anderson (2007)50 (exp 2)	M	19 M&F[e] 23.6±1.1y, mw	CO6[‡]; L[ψ];	80 min	Plain Water (300) Lemon (20g/80f) (300) Lemon (35g/65f) (300) Lemon (50g/50f) (300) Lemon (s) (300) Lemon (80g/20f) (300)	0 300 300 300 300 300	1603.9 ± 91.9 1466.8 ± 80.3 1414.2 ± 85.2 1375.1 ± 85.9 1183.2 ± 60.9 1140.5 ± 70.0	control 10.2 6.9 4.4 −7.5 −10.2	NS NS NS NS NS	control 45.7 63.2 76.3 140.2 154.5
Almiron-Roig & Drewnowski (2003)36	I	14M & 18F, 18-35y, mw	CO4; L[ψ]; All preloads also included a 100 kcal slice of toast;	135 min	*Males* sparkling water (591) orange juice (591) lowfat (1%) milk (591) cola (591) *Females* sparkling water (591) orange juice (591) lowfat (1%) milk (591) cola (591)	0 247 247 247 0 247 247 247	*lunch only* 1087±74 1122±69 1022±71 1078±71 838±66 736±61 708±63 760±63	*plus toast* control 23.9 15.5 19.7 control 15.5 12.1 18.0	<0.01 <0.01 <0.01 <0.01 NS <0.01	control −13.9 26.7 3.8 control 41.4 52.7 31.6
Birch et al. (1989)43 (exp 1)	M	10M & 14F, 45-66mo, NL	RCT[‡]; Snack	0 min 30 min 60 min	water (205) fruit drink (s) (205) diet fruit (a) (205) water (205) fruit drink (s) (205) diet fruit (a) (205) water (205) fruit drink (s) (205) diet fruit (a) (205)	0 90 4 0 90 4 0 90 4	454 397 451 521 459 458 421 388 378	control 7.3 0.1 control 5.4 −11.4 control 13.5 −9.4	NS[f] NS NS[f] <0.05 NS[f] NS	control 63.3 NA control 68.9 NA control 36.7 NA
Birch et al. (1989)43 (exp 2)	M	7M & 13F, 26-49mo, NL	CO12[‡]; Snack	0 min 30 min 60 min	water (150) fruit drink (s) (150) diet fruit (a) (150) water (150) fruit drink (s) (150) diet fruit (a) (150) water (150) fruit drink (s) (150) diet fruit (a) (150)	0 60 3 0 60 3 0 60 3	371 290 350 391 300 353 367 317 346	control −5.7 −5.0 control −7.9 −9.1 control 2.7 −5.0	NS[f] NS NS[f] <0.05 NS[f] NS	control 135.0 NA control 151.7 NA control 83.3 NA
Canty & Chan (1991)52	NS	18M & 2F, 23-37y, nw	CO4; L[ψ]	60 min	water (200) cherry drink (s) (200) diet cherry (a) (200) diet cherry (h) (200)	0 80[φ] 1[φ] 0	589±34 504±35 606±40 568±43	control −2.9 3.0 −3.6	NS[g] NS NS	control 125.0 NA NA

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First author (year) (experiment)	Funding (I,N,M)	Sample characteristics (N gender, age, wt)	Trial Type; Test Meal(s); Notes	Time Delay[a] (min)	Beverages (sweetener) (mL)	Bev. Energy (kcal)	Meal Intakes Kcal±SEM[b]	% ΔTEI [c]	P value[d]	% Comp
DellaValle et al. (2005)[h],37	N	44F, 18–60y, mw	CO6[‡]; L	w/meal	water (360) orange juice (360) 1% milk (360) cola (360) diet cola (360)	0 165 153 150 0	790±34 710±34 756±37 737±31 792±32	control 10.9 15.1 12.2 0.3	<0.001 <0.001 <0.001 NS	control 0.49 0.23 0.36 NA
Flood et al. (2006)[h],39	N	15M & 18F, 18-45y, mw	CO6; L	ad lib w/ meal	(max volume available) water (360) regular cola (360) diet cola (360) water (540) regular cola (540) diet cola (540)	(mean) 0 128 0 0 151 0	894±55 895±57 851±55 819±50 894±61 865±48	control 9.5 0.0 control 8.4 −3.3	<0.001 NS <0.001 NS	control 33.8 NA control 50.1 NA
Guss et al. (1994)51 (exp 1)	N	8 F, 20.4±1.2y, nw	CO4[‡]; L	30 min	water (500) lemon (f) (500)	0 200[φ]	589 537	control 25.1	NL	control 0.26
Guss et al. (1994)51 (exp 2)	N	8 F, 21.7±2.8y, nw	CO4[‡]; L	135 min	water (500) lemon (f) (500)	0 200[φ]	641 520	control 12.2	NL	control 0.61
Hagg et al. (1998)38	I	36M&F[e], 4-6.7y, nw	CO12; L[ψ]	Before + ad lib w/meal	water (50) 1% or 3% milk (50)	0 99	365±22 327±22	control 16.7	<0.0001	control 38.4
Holt et al. (2000)42	N	11M, 19–30y, nw	CO3; Sn, L[β] (+dinner intake)	20 min from preload to ad lib snack; 130 min from preload to lunch	mineral water (375) cola (375) diet cola (375) mineral water (375) cola (375) diet cola (375) mineral water (375) cola (375) diet cola(375)	0 150 2 0 150 2 0 150 2	*Sn* 553 502 490 *Sn + L* 1455 1263 1161 *Sn + L + D* 2903±131 2523 2642±180	*Sn* control 17.8 11.2 *Sn + L* control −4.7 −29.2 *Sn+ L+D* control −7.9 −9.0	NL NL NS NS NS NS	*Sn* control 34.3 NA *Sn + L* control 94.1 NA control 252.9 NA
Lavin et al. (1997)40	I	14F, student age, nw	CO3; Sn, L, Sn, D (+ next day intake); all snacks and meals were ad lib.	NA; drink given 4x that day;	mineral water (330) lemonade (s) (330) diet lemonade (a) (330) mineral water (330) lemonade (s) (330) diet lemonade (a) (330)	0 330 10 0 330 10	*1 day* 2962±191 2771±215 3177±215 *2 day* 4729±191 4490±191 5374±215	*1 day* control 4.7 7.6 *2 day* control 1.9 13.8	NS NS NS <0.05	*1 day* control 57.9 NA *2 day* control 72.4 NA

First author (year) (experiment)	Funding (I,N,M)	Sample characteristics (N gender, age, wt)	Trial Type; Test Meal(s); Notes	Time Delay[a] (min)	Beverages (sweetener) (mL)	Bev. Energy (kcal)	Meal Intakes Kcal±SEM[b]	% ΔTEI [c]	P value[d]	% Comp
Lavin et al. (2002)83	I	10M & 10F, age NL, mw	CO4; L$^{\psi}$	5 min	water (150) current drink (s) (150)	0 60	859±49 884±47	control 9.9	*meal only* NS	control −42.2
Mattes (1996)[i],12	NL	8M & 8F, 21y+, nw (uses wt for ht)	CO5; 2day (d) diet records. d1=control, d2= preload; preloads included crackers & cheese	NA	water (1008) cola (1008)	0 418	NL NL	*d2 vs. d1* −1.7 7.2	NS <0.05	NA −12.5
Rodin (1990)[j],46	I	10M & 10F, 22-50y, mw	CO4; L$^{\beta}$	38 min	water (500) lemonade (g) (500) lemonade (f) (500) diet lemonade (a) (500)	0 201 201 4	1192 1102 897 1217	control 9.2 −7.9 2.4	<0.05 NS (<0.06) NS	control 45.1 147.0 NA
Rogers et al. (1988)[h],47	NL	4M & 8F, 19-25y, nw	CO5; L$^{\beta\psi}$	65 min	water (200) sweet water (g) (200) diet water (a) (200) diet water (h) (200) diet water (k) (200)	0 188 3 0 0	1443 1274 1333 1387 1400	control 1.3 −7.4 −3.9 −3.0	NS NS NS NS	control 89.9 NA NA NA
Rolls et al. (1990)45	N	14M, 21–39y, nw 14M, 21–39y, nw 14M, 21–39y, nw	CO7‡, L	w/ meal 30 min 60 min	water (237) lemonade (s) (237) diet lemonade (a) (237) water (473) lemonade (s) (473) diet lemonade (a) (473) water (237) lemonade (s) (237) diet lemonade (a) (237) water (473) lemonade (s) (473) diet lemonade (a) (473) water (237) lemonade (s) (237) diet lemonade (a) (237) water (473) lemonade (s) (473) diet lemonade (a) (473)	0 83 5 0 166 10 0 83 5 0 166 10 0 83 5 0 166 10	1083±90 1138±71 1022±79 1077±88 1046±81 1113±74 1137±148 1098±109 1093±102 1199±160 1096±132 1138±141 1147±73 1104±59 1211±37 1225±67 1134±62 1140±64	control 12.7 −5.2 control 12.5 4.3 control 3.9 −3.4 control 5.3 −4.2 control 3.5 6.1 control 6.1 −6.1	<0.01 NS <0.01 NS NS NS NS NS NS NS NS NS	control −66.4 NA control 19.0 NA control 47.0 NA control 61.6 NA control 51.5 NA control 55.2 NA
Shafer et al. (1987)[k],48 (exp 1)	N	4M & 5F, 35-54y, NL	CO5‡; L$^{\beta}$	60 min	water "solution" (g) (NL) "solution" (s) (NL) "solution" (f) (NL)	0 100 100 100	920 831 820 889	control 1.2 0.0 7.5	*meal only* NS NS NS	control 89 100 31

First author (year) (experiment)	Funding (I,N,M)	Sample characteristics (N gender, age, wt)	Trial Type; Test Meal(s); Notes	Time Delay[a] (min)	Beverages (sweetener) (mL)	Bev. Energy (kcal)	Meal Intakes Kcal±SEM[b]	% ΔTEI [c]	P value[d]	% Comp
Shafer et al. (1987)[k],48 (exp 2)	N	5F, 25–65y, NL	C05‡; L[β]	60 min	water diet “solution” (a) (100)	water 1	899 860	control −4.2	*meal only* NS	control 536
Spitzer & Rodin (1987)[j],49	NL	21M & 19F, ~20–25y, mw	RCT‡;L[β]	135 min	water (500) lemonade (g) (500) lemonade (f) (500)	0 197 197	1102 1405 877	control 45.3 −2.5	<0.05[1] NL	control −153.5 114.7
Van Wymelbeke et al. (2004)[m],41	N	12M & 12F, 20-25y, nw	CO6; L, D	NA Drank 2L over course of day	*(wks 1, 7, 9 averaged)* mineral water (2000) fruit drink (s) (2000) *(wks 2, 8, 10 averaged)* mineral water (2000) diet fruit (a,h,k) (2000)	0 799 0 0	2279 2035 2255 2120	control (d2) 24.3 (d1) control (d2) −6.0 (d1)	<0.05[l] NS	control 30.7 control NA

Abbreviations: I=industry, N=Non-industry, M=mixed (both industry and non-industry), nw=normal weight , ow=overweight, mw=mixed weight, CO#=crossover and # of repeated experiments, B=Breakfast, L=Lunch, D=Dinner, NA= Not Applicable, NL=Not listed, NC=not calculable, NS=not significantly different (P>0.05), %ΔTEI=Percent change in Total Energy Intake. Sweeteners: s=sucrose, g=glucose, f=fructose, a=aspartame, h=saccharin, k=acesulfame-K.

‡See Also Table 2 for further results from this study.

†Beverages with non-conventional caloric sweeteners or mixed caloric and diet sweeteners not shown.

βtest meal included caloric beverages

ψtest meal included water

φbeverage kcal not listed; kcal were calculated at 4kcal/g for sucrose, glucose, fructose, aspartame and 2.5kcal/g for xylitol, and 0kcal/g for saccharin.

[a]Time delay = minutes from preload to test meal(s)

[b]SEM was not available for all studies. SEM was calculated from SD (SEM=SD/√N) where available. Where stratified results were combined, SEM was not calculated.

[c]Total energy intake includes combined kcal from preload and test meal. %ΔTEI is calculated as 100*(TEI(w/beverage)−TEI(w/water)) / TEI (w/water).

[d]P values reflect differences in total energy intake. I.e. Preload+meal kcal compared to water+meal kcal. This comparison was not available for all studies. For diet beverages with negligible calories, P-values for meal intake contrasts are considered equivalent.

[e]Sex specific N’s not listed

[f]Total intake differences not tested. Amount of compensation was not significantly different from preload calories.

[g]Non-significant P value was reported for differences in test meals only; However total energy differences were smaller than meal differences, so non-significance was assumed.

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[h] Additional data supplied by author(s)

[i] Paper listed only differences in intake between day 1 (control) and day 2 (test day). Percent change in intake was calculated from differences. Day 1 intake was estimated from figure.

[j] Totals were calculated from weighted averages of stratified results as there were no significant differences by sex and/or wt.

[k] Paper does not specify any flavoring or volume for preload solution. First author has passed away, and collaborators were contacted but were unable to provide this information.

[l] Significant P value was reported for differences in test meals only; However total energy differences were of greater magnitude and significance was assumed.

[m] Caloric intake was measured over 48 hours. Beverages were consumed the first day, still mineral water was consumed the second day. Breakfast calories were fixed. Lunch and Dinner calories were ad lib.