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Under What Conditions do Water-Intervention Studies Significantly Improve Child Body Weight?

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Abstract
There are particular conditions that may optimize the effects of drinking-water interventions on body weight change and risk of obesity. Strategic planning to create and sustain conditions for optimal effects of drinking water may maximize the impact of school-based interventions to reduce childhood obesity. This paper proposes questions about the target population, type of diet and activity level that will be maintained during the intervention, and planned intervention message(s). The proposed questions are motivated by conditions associated with significant effects of drinking water in randomized controlled trials. They are discussed in relation to conditions underlying the recently successful school-based drinking-water intervention in New York City. If conditions allow, school-based drinking-water interventions have the potential to efficiently benefit millions of children worldwide, who are at risk of becoming obese.

School-based water interventions are recommended as an evidence-based method to address childhood obesity [1]. Randomized controlled trials (RCTs) in 6 schools in the United Kingdom and 32 schools in Germany report that drinking-water intervention prevents increases in the prevalence of childhood overweight or obesity [2, 3]. In observational data from over 1,000 schools in New York City (NYC), installation of drinking water stations (Water Jets) is associated with significantly smaller increases in body mass index (BMI) z-score and prevalence of overweight and obesity [4].

Despite evidence suggesting that school-based water interventions can efficiently promote healthy weight for millions of children in communities around the world, particular conditions may be necessary for this effect. Depending on the initial weight status of the target population, the type of diet and the level of physical activity sustained during the intervention, and content of intervention message(s), drinking-water interventions can have negative, null, or positive effects on body weight outcomes [5]. Many water interventions, in fact, report null effects on body weight outcomes. In a recent review of randomized controlled water interventions, 83 out of 115 reported effects are null effects [5]. The expectation that simple drinking-water interventions will prevent or reduce childhood obesity may not be met, if conditions necessary for invoking an effect are not specified in the intervention design.

This paper aims to motivate strategic planning to create and sustain conditions in communities that optimize water interventions to reduce childhood obesity. The fol-

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Table 1. Conditions associated with negative, null, and positive effects of drinking water on body weight outcomes in randomized controlled trials involving children or adolescents

Population		Conditions during intervention		Type of beverage intervention		RCT outcome
age, years	weight status	diet	physical activity	type of increase in drinking water	intervention message	weight change effect
7–18	NO	Ad libitum	Usual	Relative	Drink water instead of SSB only	No effect
7–15	O	Ad libitum	Usual	Relative	Drink water instead of SSB and juice Drink water instead of SSB, skimmed and low-fat milks Drink water instead of SSB only	Less weight gain Less weight gain Less weight gain
7–9	NO	Ad libitum	Usual	Absolute	Drink 1 glass/day more plain water	No effect
9–12	O	Restricted	Usual	Absolute	Diluted urine by 297 mmol/kg	No effect
9–12	O	Restricted	Usual	Absolute	Diluted urine by 706 mmol/kg	More weight loss

RCT, randomized controlled trial; O, overweight or obese participants; NO, normal weight participants; SSB, sugar-sweetened beverages.

lowing paragraphs summarize conditions associated with different effects of drinking water in RCTs, propose questions about local conditions for planners to consider as they design water interventions, and describe the success of the NYC Water Jet installation in relation to the RCT literature and proposed questions.

Conditions for Effect in RCTs

Table 1 summarizes conditions associated with negative, null, and positive effects of drinking water on body weight outcomes in RCTs involving children or adolescents [5]. RCTs that report significantly reduced weight gain involve study participants who were overweight or obese before the intervention, an ad libitum diet during the intervention, and intervention messages that induce a relative increase in drinking water instead of caloric beverages. In short-term controlled experiments, these conditions result in significant decreases in total energy intake and increases in fat oxidation [5]. Drinking water instead of caloric beverages with meals increases the likelihood of metabolizing fat consumed in the meal before the next meal [6].

RCTs where drinking water resulted in significantly increased weight loss involved study participants who were overweight or obese at baseline, who were on a restricted hypocaloric or low glycemic experimental diet during the intervention, and who were given a beverage change instruction to increase the intake of drinking water by 1 L/day or more or enough to dilute urine below 500 mmol/kg [5]. Drinking water causes transient hypo-osmotic cell swelling, which activates osmosensitive neural pathways, which are hypothesized to drive thermogenesis [7, 8]. In healthy, fasted individuals, hypo-osmotic cell swelling counteracts protein and glycogen breakdown in the liver, decreases blood glucose and insulin concentrations, and increases lipolysis and lipid oxidation [9].

Questions to Guide Water Intervention Planning and Evaluation

Conditions associated with reduced weight gain or increased weight loss effects of drinking water in RCTs suggest questions for planners to consider when designing water interventions against obesity (Table 2).

Is the Target Population Normal Weight, Overweight, or Obese?

In normal-weight participants, if sugar-sweetened beverage intake is already low, interventions to drink water instead of sugar-sweetened beverages may be ineffective [10]. Overweight or obese status may reflect the intake of various kinds of caloric beverages, low water intake, greater osmotic stress on cells [11, 12], and/or metabolic inflexibility [7]. Each of these factors might modify intervention effectiveness. If the target population includes normal weight and overweight or obese individuals, the evaluation protocol should collect data about potential modifying factors and plan to stratify analyses by weight status at baseline.

Table 2. Questions to inform drinking water intervention planning and evaluation

Question	Implication for intervention design
Is the target population normal weight, overweight, and/or obese?	If the protocol will include normal weight and overweight or obese individuals, plan to check for effect modification by initial weight status in the evaluation
Does the target population eat ad libitum or restrict food intake?	If the diet is restricted, intervention messages to increase absolute water intake may be effective. If the diet is ad libitum, intervention messages to increase relative water intake (i.e. drink water instead of other beverages) may be effective
Will the target population drink water instead of all caloric drinks?	Intervention protocol to increase relative water intake should explicitly handle all types of caloric beverages, either through clear instruction for intervention participants, when/how/why to avoid caloric drinks, or systematic reduction in the availability of caloric beverages
Will the drinking water intervention increase the total volume of water consumed?	For absolute beverage change interventions, specify a threshold volume of drinking water that improves hydration status (e.g., dilutes urine osmolality)
Does the target population eat high glycemic foods or high fat foods?	Consider ways to limit the intake of high glycemic foods and/or high fat foods during the intervention, and/or plan to track intake of these foods over time and check for effect modification in the evaluation analyses
Does the target population have a low level of physical activity?	Consider ways to increase physical activity, and/or plan to track physical activity level over time and check for effect modification in the evaluation analyses
What knowledge, beliefs, policies, or practices explain answers to the above questions?	Community-wide partnerships may be critical for creating conditions favorable for effective drinking water intervention (e.g., to enable dissemination of information, policy change, and funding allocation)

Does the Target Population Eat Ad Libitum or Restrict Food Intake?

The ad libitum diet condition is key to observing the relative effects of drinking water instead of caloric beverages on energy intake. People with ad libitum diets automatically consume excess energy when they drink any caloric beverage with meals, instead of drinking water. This happens because individuals do not unconsciously decrease the amount of food they consume to compensate for the beverage calories [13]. In contrast, people who are consciously restricting calories deliberately adjust food intake to consume the prescribed target total energy [14, 15]. If the target population includes restricted or restrained eaters, intervention effectiveness may depend on messages about absolute increases in drinking water.

Will the Target Population Drink Water Instead of Caloric Drinks?

Under the conditions of an ad libitum diet, the intake of drinking water instead of caloric beverages consistently results in significantly lower energy intake [5]. In the experiments that characterize this effect, drinking water replaces all other caloric beverage options, *by design*. In these experiments, drinking water does not displace other beverages by chance. Interventions aiming to leverage this effect should explicitly specify when, how, and why drinking water will replace all other (or at least most) caloric beverages. Although drinking water sometimes displaces caloric beverages [e.g., 16], leaving displacement up to chance may jeopardize the impact of the intervention.

Will the Drinking-Water Intervention Increase the Total Volume of Water Consumed?

Absolute effects of drinking water on fat oxidation are reported by short-term studies that compare 0.5–3.5 L drinking water with no fluid intake. These studies also observe improvement in cell hydration [5]. The effect appears to be contingent on fasting glucose and insulin levels [5]; so it may be observed in people only with documented fasting periods or hypocaloric diet. Absolute water intake requirements vary from person to person and over time [17]. Increases in absolute water intake may be difficult to induce, given the lack of thirst and/or lack of restrooms [18]. Hydration measures, such as urine osmolality, are available to index how much water is necessary to reduce osmotic stress on cells.

Does the Target Population Eat High Glycemic Foods or High Fat Foods and/or Have Low Activity Levels?

Food composition and physical activity may modify the effects of drinking water on the net fat balance. Drinking water favors fat oxidation by limiting exogenous carbohydrate and protein from beverages, by limiting endogenous glucose and amino acids from glycogen and protein breakdown, and by improving glucose clearance by reversing insulin insensitivity due to cell shrinkage and/or increasing energy expenditure [7–9]. Because some effects of drinking water on fat oxidation are mediated by lower blood glucose and insulin, the effects of drinking-water interventions on weight change may be magnified by a diet of low glycemic foods, and blunted by the intake of high glycemic food [19]. Given that the net fat balance is a function of fat oxidation and fat intake, a high fat intake may mask benefits of water on the fat oxidation rate. Also, given that net fat balance is tied to net energy balance, low levels of physical activity resulting in positive energy balance may prevent negative fat balance.

What Knowledge, Beliefs, Policies, or Practices Explain the Answers to the Above Questions?

Many factors determine conditions for school intervention success, including school staff training, equipment, parent expectations, food supply contracts, funding requirements, and local, state, and national policies. Shared understanding about the conditions required for intervention effectiveness can inform community collaboration, funding, and policy to create and sustain conditions where drinking water is most likely to decrease total energy intake and/or increase energy expenditure or fat oxidation.

Is the Effect of Water Jet Installation in NYC Schools Consistent with Effects of RCTs?

Several RCTs report effects of school-based drinking-water interventions on body weight outcomes in children or adolescents [2, 3, 20, 21]. Similar to the NYC Water Jet installation [4], the target population in these RCTs comprised all children in school, regardless of their weight status. The implicit diet and activity conditions in these RCTs were ad libitum (unrestricted) diet, and non-athlete levels of exercise. The school-based RCTs tested messages about drinking water instead of sugar-sweetened beverages [2, 20, 21] or messages about the water needs of the body and water circuit in nature [3].

Unlike the NYC Water Jet installation, the school-based RCTs report null or adverse effects on BMI change [2, 3, 20, 21]. Following the intervention to discourage fizzy drinks and promote drinking water in 6 schools in the United Kingdom, James et al. [2] reported "no significant change in the difference in BMI or z-score" for the whole study sample of 644 children. Simple messages encouraging water consumption instead of sugar-sweetened beverages consumption for 1,140 children in 22 schools in Brazil, resulted in "a statistically significant decrease in the daily consumption of carbonated drinks ... followed by a non-significant overall change in BMI [20]." In the Netherlands, intervention to reduce sugar-sweetened beverage intake by promoting water in 4 schools resulted in a significantly higher increase of BMI in the intervention group compared to the control group [21]. In Germany, 32 schools, including 2,950 children, were randomized to receive installation of drinking water fountains, water bottles, 4 water lessons, and encouragement for teachers to organize water bottle filling for all children each morning, or no intervention [3]. The water fountains provided cool, filtered, plain, or carbonated water. Although drinking water increased significantly by an average of 1 glass/day, the "estimated group difference in BMI SDS change of –0.004 was not significant ($p = 0.8$)" [3].

In contrast to the RCTs in Germany and the United Kingdom [2, 3], where 25% and 20% of the study participants were overweight or obese prior to intervention, respectively, in the NYC schools before installation of the Water Jets, the prevalence rate of overweight or obesity was 39% [4].

In the school-based RCTs [2, 3, 20, 21], caloric beverages other than sugar-sweetened beverages were not spontaneously displaced or restricted. In Brazil, increases in juice intake negated intervention effects on sugar-sweetened beverage intake. In Germany, the significant increase in drinking water (during class or mid-morning) had no effect on juice or soft drink consumption. The design of school-based RCTs did not explicitly specify or account for the total beverage volume or pattern.

Unlike conditions in the school-based RCTs, in the NYC schools, the availability of caloric beverages other than sugar-sweetened beverages was deliberately limited. Beginning in 2001, NYC implemented policies to remove soda from vending machines, replace whole milk with low-fat milk, and limit available beverages to those with less than 10 cal/8oz serving. All schools made these changes before 2009–2010, prior to the Water Jet installation. After the Water Jet installation in 2010–2013, purchases of fat-free chocolate milk decreased significantly by 14 half pints per student per year [4].

The significant effect of Water Jet installation on BMI in NYC is consistent with results from dozens of controlled crossover experiments indicating that total energy intake is significantly reduced and postprandial fat oxidation is significantly increased, when individuals consume drinking water instead of any kind of caloric beverage, with ad libitum food [5]. Sugar-sweetened beverages, juice, sweetened milks, soy milk, plain milks, sports drinks, and alcohol all differ significantly from drinking water in these aspects [22–25].

Drinking plain milk instead of water has been estimated to increase the total energy intake of preschoolers by an average of 17% [23]. The addition of milk to a low-glycemic meal has been observed to significantly increase postprandial insulinaemia. "Even an ordinary amount of milk (200 mL) increased the insulin area under the curve to the same level as seen with white bread" [19]. Milk intake results in weight gain, like sugar-sweetened beverage intake [26, 27]. Milk facilitates weight management when it replaces food in the diet [28], not when it replaces drinking water.

In non-school-based RCTs involving only overweight or obese adolescents, with ad libitum diet and non-athlete levels of physical activity, drinking water instead of sugar-sweetened beverages and juice results in significantly decreased total energy intake and reduced weight gain [29]. Drinking water instead of sugar-sweetened beverages and milk reduces weight gain [30]. Over 12 weeks, instruction to drink 1 L/day skim milk results in significant increases in the BMI z-score compared to instruction to drink 1 L/day water [30]. Although not instructed to do so, participants assigned to drink 1 L/day water significantly decreased intake of low fat milk (by –0.8 g/kg BWT) and sugar-sweetened beverages (by –2.6 g/kg BWT), and significantly reduced total energy intake (by –991 kJ/day) [17]. Participants assigned to drink 1 L/day skim milk similarly, spontaneously reduced intake of sugar-sweetened beverage intake (by –2.2 g/kg BW), but the displaced calories from sugar-sweetened beverages were offset by increased calories from skim milk.

Although the school-based RCTs report no significant effect on the *mean change* in BMI, they do report significantly smaller increases in the *prevalence of overweight or obese* children [2, 3]. This result is consistent with the effect of the NYC Water Jet installation on the percent of overweight or obese children. In the United Kingdom, the prevalence of overweight or obesity increased by 7.5% in control schools but remained stable, with an increase of only +0.2% in intervention schools [2]. In Germany, the prevalence of overweight or obesity increased from 25.9 to 27.8% in control schools but increased by only +0.1% in intervention schools (23.4–23.5%). In Germany, "there was no general weight reducing effect. (However), children with a body weight close to the cutoff point for overweight received the greatest benefit [3]." In Brazil, the school-based RCT resulted in significantly smaller increases of BMI in the sub-sample of children who were overweight or obese before the intervention [20]. Significant effects of school-based RCT appear to be contingent on initial BMI.

It remains to be determined if and how participant weight status modifies the effects of drinking-water interventions. It also remains to be confirmed if the conditions described above, which are associated with beneficial effects of drinking water in the aforementioned RCTs, actually cause positive intervention outcomes. Although the drinking water treatments were randomly assigned in the above RCTs, the intervention contexts were not. Further research is needed to characterize optimal design(s) for developing drinking-water interventions against obesity.

Available data suggest that, if conditions allow, drinking-water interventions, such as the Water Jet installation in NYC [4], have the potential to efficiently benefit millions of children worldwide who are at risk of obesity. The success of drinking-water interventions may depend on the initial weight status, total beverage intake pattern, dietary restraint, diet composition, and activity level of the target population.

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