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Beverages contribute extra calories to meals and daily energy intake in overweight and obese women

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Abstract

Caloric beverages may promote obesity by yielding energy without producing satiety, but prior laboratory and intervention studies are inconclusive. This study examined whether the diets of free-living overweight and obese women show evidence that calories from beverages are offset by reductions in solid food within individual eating occasions and across entire days. Eighty-two women weighed and recorded all consumed foods and beverages for seven days. Beverages were coded as high-calorie (>0.165 kcal/g) or low-calorie (<0.165 kcal/g), and total energy intake and energy intake from solid food were calculated for each eating occasion and day. In covariate-adjusted models, energy intake from solid food did not differ between eating occasions that included high-calorie or low-calorie beverages and those with no reported beverage. Energy intake from solid food was also unrelated to the number of high-calorie or low-calorie beverages consumed per day. On average, eating occasions that included a high-calorie beverage were 169 kcal higher in total energy than those with no reported beverage, and 195 kcal higher in total energy than those that included a low-calorie beverage. Each high-calorie beverage consumed per day contributed an additional 147 kcal to women's daily energy intake, whereas low-calorie beverage intake was unrelated to daily energy intake. Beverages contributed to total energy intake

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in a near-additive fashion among free-living overweight and obese women, suggesting a need to develop more effective interventions to reduce caloric beverage intake in the context of weight management, and to potentially reexamine dietary guidelines.

Keywords

Beverages; Food form; Obesity; Dietary compensation; Satiety

1. Introduction

The obesity epidemic has largely resulted from changes in dietary consumption patterns [1, 2]. In particular, beverages have increased in portion size by 25–34% since the late 1970's and become more readily available in the environment [3–6]. As a result, the percentage of daily energy from caloric beverages has increased by 135% over the past 3 decades [7]. Despite the compelling temporal trends implicating caloric beverages in the obesity epidemic, the scientific literature remains unclear with respect to the contribution of caloric beverages to total energy intake and body weight at the individual level. Two meta-analyses found small but significant overall associations between intake of sugar-sweetened beverages and total energy intake and body weight [8, 9], whereas two more restrictive meta-analyses that excluded cross-sectional studies reported that the association between sugar-sweetened beverage intake and weight gain was “inconclusive” [10] or “near zero” [11].

In the absence of a conclusive link between caloric beverage intake and body weight, attention has shifted to examining whether individuals consume less solid food to offset the energy obtained from caloric beverages. If reductions in solid food intake do not fully offset the energy consumed from beverages, caloric beverages would have a positive net effect on energy balance and promote weight gain. Most studies addressing this question administered beverages or solid foods, often matched on energy and macronutrient content, and then assessed whether individuals consumed less solid food at a subsequent test meal. Results are mixed; some studies report that consuming caloric beverages led to smaller reductions in subsequent test meal intake than consuming solid foods [12–15], suggesting weak dietary compensation for caloric beverages, whereas others did not support this pattern [16]. Importantly, the time interval between beverage consumption and test meal intake may affect the degree of observed compensation since beverages are found to be less satiating than solids at longer delays [17]. However, minimal compensation has also been observed for beverages consumed *simultaneously* with solid food [18].

The existing literature has four major limitations. First, most studies involved mandated consumption of specific beverages and/or solid foods, or assessed compensation using a standardized test meal presented in highly-controlled laboratory settings. These designs have limited generalizability to real world settings where greater food variety can trigger eating in the absence of hunger [19, 20]. Second, studies often examined the effect of beverages on intake at subsequent test meals, which differs from the common practice of consuming beverages with solid food during a meal. Third, laboratory studies are limited in duration, and do not provide information on dietary compensation for beverages across an entire day. Finally, very few studies have specifically examined dietary compensation for caloric beverages in overweight and obese individuals, a group that may have a reduced compensation for beverages [21] and for whom the potential effects of caloric beverages on energy intake are particularly relevant to weight management.

The aim of this observational study was to test the hypothesis that compensation for caloric beverages occurs within eating occasions and across days. Free-living overweight and obese women weighed and recorded all foods and beverages consumed over seven consecutive days. Consistent with dietary compensation, we hypothesized that individuals would exhibit lower intake of solid food to offset the energy consumed from beverages, resulting in no overall difference in total energy intake within the same eating occasion or within the same day. Dietary compensation would be apparent in four hypothesized patterns of association:

1. Energy intake from solid food would be lower at eating occasions that included a high-calorie beverage compared to eating occasions with no reported beverage or a low-calorie beverage.
2. Total energy intake at eating occasions that included a high-calorie beverage would not significantly differ from eating occasions with low-calorie beverages or no beverage.
3. Daily energy intake from solid food would be inversely associated with the number of high-calorie beverages consumed, and unrelated to the number of low-calorie beverages consumed.
4. No association was expected between the number of high-calorie or low-calorie beverages consumed and total daily energy intake.

2. Methods

2.1. Participants

Overweight and obese women were recruited for a study on behavioral predictors of dietary intake between 2008–2010 [22] through study advertisements posted on medical center campuses and online posting forums. Women aged 18 to 45 years with a body mass index (BMI) between 25.0–39.9 kg/m² were eligible for participation. Exclusion criteria included recent dieting, major food allergies or sensitivities, pregnancy or lactation in the past six months, symptoms of eating pathology in the past 5 years, clinically significant symptoms of depression, anxiety, or mania in the past 30 days, bariatric surgery, peri- or post-menopausal status, or medical conditions or medications affecting appetite, metabolism, or digestion. Eligibility criteria were assessed through an initial telephone screening interview. Study procedures received Institutional Review Board approval.

2.2. Procedures

Participants completed two laboratory visits. In the first visit, written consent was obtained and height and weight were assessed as a final step in verifying eligibility. Participants were trained to complete weighed diet records using plastic food models, a portable, digital food scale (model # P115, Escali, Minneapolis, MN), and record forms with spaces for each item's description, brand or source, preparation method, time of consumption, amount consumed (in grams), and whether it was consumed as a meal, snack, or beverage consumed alone. Weighed diet records are preferable to other methods, such as 24-hour diet recalls and food frequency questionnaires, for quantifying actual dietary intake within a particular period of time [23, 24]. Participants were not required to record water intake because this can be burdensome and difficult for participants, and water consumption does not affect solid food intake or satiation at a meal [18, 25–27]. Participants were asked to complete seven consecutive days of diet recording. Research assistants contacted participants by telephone twice between visits to promote compliance with the diet record protocol. During the second study visit, diet records were reviewed for completeness and any ambiguities were resolved. Participants were then debriefed and compensated \$50 for their time.

2.3. Measures

2.3.1. Body mass index (BMI)—BMI (kg/m^2) was calculated from height and weight measured in light clothing and without shoes using a balance beam scale and stadiometer.

2.3.2. Socioeconomic and demographic variables—Participants self-reported age, education level (baccalaureate degree vs. less than baccalaureate degree), household income (\$0–\$29,999; \$30,000–\$59,999; \$60,000–\$89,999; \$90,000 and above), race/ethnicity (Asian; Black/African-American; Hispanic; Multi-ethnic/Other; Non-Hispanic, White), and marital status (single, separated or divorced vs. married or living with partner).

2.3.3. Physical activity—The self-administered short-form of the International Physical Activity Questionnaire [28] was used to assess occupational and leisure time physical activity during the seven days during which dietary intake was recorded. For each subject, average daily minutes spent engaged in moderate and vigorous physical activity (combined) was calculated.

2.3.4. Dietary intake—Analysis of diet record data was completed using Food Processor SQL version 10.5.0 (Esha Research, Salem, OR). A research assistant used item descriptions and weights provided by participants to identify and enter all consumed foods and beverages. Plate waste and inedible portions of foods (e.g., apple cores) were accounted for through subtraction. Foods sharing the same time of day on the diet record were considered to belong to the same eating occasion. A registered dietitian reviewed all dietary data for accuracy.

Given our interest in understanding the role of beverages in energy intake in an overweight and obese population, we categorized beverages based solely on energy content. Though this categorization system does not capture differences in beverages' nutrient content, research has shown that mode of consumption (i.e., drinking a liquid versus eating solid food) is the primary driver of satiety, regardless of nutrient content or other properties [14, 27]. High-calorie and low-calorie beverages were distinguished in a bottom-up fashion based on their energy density (kcal/g). A histogram of reported beverage energy densities (Figure 1) contained a natural break point in the distribution at approximately 0.165 kcal/g , with all “diet” and unsweetened beverages falling at or below 0.165 kcal/g . Therefore, beverages with an energy density at or below 0.165 kcal/g were categorized as low-calorie beverages, whereas those above 0.165 kcal/g were categorized as high-calorie beverages. Eating occasions were classified as including a high-calorie beverage, a low-calorie beverage, or no reported beverage. Twenty-three eating occasions that included both high-calorie and low-calorie beverages were classified as including a high-calorie beverage. The total numbers of low-calorie and high-calorie beverages consumed per day were calculated.

2.4. Data analysis

Statistical analyses were conducted in 2012 using Stata 11 (StataCorp, LLC, College Station, Texas). Variable distributions were examined for skew and outlying cases. Descriptive statistics were used to characterize the sample and dietary intake variables. Two-sample t-tests compared low- and high-calorie beverages on energy and energy density.

Linear mixed models were used to test associations between beverage consumption and total energy intake within eating occasions and within days. Hypothesis 1 (solid food intake within eating occasions) was tested by comparing eating occasions that included a high-calorie beverage, low-calorie beverage, or no reported beverage on the energy consumed from solid food. This analysis excluded 183 observations that consisted solely of beverages consumed without solid food. Hypothesis 2 (total energy intake within eating occasions) was

tested in a model similar to that for Hypothesis 1, but with total energy intake at each eating occasion as the dependent variable. These models included age, BMI, education, income, ethnicity/race, physical activity, marital status, and eating occasion type (meal vs. snack) as covariates. Following a “top-down” model building strategy [29], the effects of beverage intake on energy intake were allowed to vary randomly by participant. An independent residual structure was applied.

Hypothesis 3 (solid food intake within days) was tested in a third set of models that examined associations between energy intake from solid food and the numbers of high-calorie and low-calorie beverages consumed on a given day, with each participant contributing up to seven days of data to the analysis. Hypothesis 4 (total energy intake within days) was tested by modeling associations between the number of high- and low-calorie beverages consumed and total daily energy intake. Due to the sparseness of the data, one day that included six high-calorie beverages and two days that included four low-calorie beverages were not analyzed. Models included age, BMI, education, income, ethnicity/race, physical activity, and marital status as covariates. As above, effects were allowed to vary randomly across participants and an independent residual structure was applied.

3. Results

Of the 94 women who enrolled in the study, 4 did not return for the second study visit and 7 did not return properly completed diet record data. One subject's diet record data were excluded due to implausibly low intake (2–4 food items per day). Therefore, data from 82 women were analyzed (Table 1). One extreme value for energy intake within an eating occasion (3,203 kcal), and two extreme values for daily energy intake (5,236 and 4,705 kcal) were excluded from analyses.

Adherence to the diet record protocol was relatively high among subjects included in the analyses, with 82% of participants providing all 7 days of diet records, 10% providing 6 days, 4% providing 5 days, and 5% providing 4 days of diet records. In total, 2,188 eating occasions were recorded by participants over 547 days (Table 2). A total of 3,729 non-beverage food items were reported, with a mean energy density of 2.1 (SD=1.5) kcal/g. Food items provided a mean of 212.3 (SD=208.4) kcal per item. Of the 2,188 eating occasions recorded, 594 (27.1%) eating occasions included a high-calorie beverage, 217 (9.9%) included a low-calorie beverage, and 1,377 (62.9%) included food consumed with no reported beverage (Table 2).

Participants collectively reported 852 consumed beverages, 254 (29.8%) of which were low-calorie beverages. High-calorie beverages had a higher energy density ($M=0.5$ kcal/g, $SD=0.3$ kcal/g) than low-calorie beverages ($M=0.03$ kcal/g, $SD=0.04$ kcal/g), $t(850)=27.3$, $p<.0001$, and provided more energy per beverage ($M=159.2$ kcal, $SD=126.6$ kcal) than low-calorie beverages ($M=12.7$ kcal, $SD=18.1$ kcal), $t(850)=18.36$, $p<.0001$.

Hypothesis 1 was not supported in a fully-adjusted model that compared eating occasions with high-calorie, low-calorie, or no reported beverages on energy intake from solid food. Eating occasions that included a high-calorie beverage did not significantly differ from those with no reported beverage (estimate: 13.7 kcal, 95% C.I.: -15.2, 42.7 kcal), and were actually higher in energy intake from solid food than eating occasions with a low-calorie beverage (estimate: 51.8 kcal, 95% C.I.: 3.2, 100.4 kcal). Eating occasions that included a low-calorie beverage did not significantly differ from those with no reported beverage in the amount of energy from solid food (estimate: -38.0 kcal, 95% C.I.: -82.3, 6.2 kcal).

Similarly, findings did not support hypothesis 2, which predicted no difference in total energy intake for eating occasions with high-calorie, low-calorie, and no reported beverages.

Eating occasions that included a high-calorie beverage were significantly higher in total energy than eating occasions with no reported beverage (estimate: 168.6 kcal, 95% C.I.: 138.7, 198.5 kcal) or a low-calorie beverage (estimate: 194.5 kcal, 95% C.I.: 144.2, 244.7 kcal; Figure 2). Eating occasions with low-calorie beverages did not differ in total energy from those with no reported beverage (estimate: -25.9 kcal, 95% C.I.: -71.6, 19.9 kcal).

A similar pattern was observed when examining dietary intake across entire days. In contrast to the inverse association between high-calorie beverage and solid food consumption predicted by hypothesis 3, daily energy intake from solid food was not associated with the number of high-calorie beverages consumed (estimate: -9.6 kcal, 95% C.I.: -59.1, 39.9 kcal). Daily energy intake from solid food was also unrelated to consumption of low-calorie beverages that same day (estimate: 69.1 kcal, 95% C.I.: -5.5, 143.7 kcal).

Findings also refuted hypothesis 4, which suggested no difference in total daily energy intake according to the number of high-calorie beverages consumed (Figure 3). In covariate-adjusted models, each additional high-calorie beverage consumed per day contributed an average of 147.3 (95% C.I.: 96.4, 198.2 kcal) additional calories to total daily energy intake, whereas the number of low-calorie beverages consumed per day was not significantly related to total daily energy intake (estimate: 38.7 kcal, 95% C.I.: -40.4, 117.7 kcal).

4. Discussion

Dietary intake data from free-living overweight and obese women showed no evidence of compensation for caloric beverages. Participants did not reduce their solid food intake based on the presence of a high-calorie beverage within an eating occasion, or according to the number of high-calorie beverages consumed per day, as would be expected in the presence of dietary compensation. Both within individual eating occasions and across days, consumption of high-calorie beverages contributed almost the exact amount of calories to energy intake (169 kcal and 147 kcal, respectively) that would be expected based on the average energy content of high-calorie beverages (159 kcal). From these findings, we conclude that consumption of high-calorie beverages in free-living overweight and obese women contributes to the total energy content of individual eating occasions and total daily energy intake in a near-additive fashion, consistent with the absence of any significant compensation for caloric beverages. In contrast, consumption of low-calorie beverages was unrelated to energy intake within eating occasions or across days.

This study complements prior laboratory and intervention studies, which have yielded inconsistent findings, by examining dietary compensation for caloric beverages in free-living individuals. Dietary compensation for beverages may be strongly influenced by a variety of contextual and cognitive factors. For example, perceiving a sweetened, energy-dense beverage as a “meal replacement” is likely to elicit a higher degree of dietary compensation relative to regular high-calorie beverages [30]. At least part of the difference in the satiating properties of solid foods compared to liquids is attributable to expectancy effects, as informing someone that solid food takes liquid form in the stomach, or vice versa, influences satiety [31]. The present study suggests that compensation for caloric beverages may be even lower in real-world settings than previously observed in some laboratory and intervention studies [21, 32], which may be attributable to contextual and cognitive factors that are absent in other study designs.

The current findings add to a growing literature that suggests federal dietary guidelines should explicitly recommend reductions in caloric beverage consumption for overweight and obese individuals seeking to lose weight. The 2010 Dietary Guidelines Advisory Committee concluded that “a limited body of evidence shows conflicting results about

whether liquid and solid foods differ in their effects on energy intake and body weight” [33]. As a result, the 2010 guidelines [34] discourage intake of sugar-sweetened beverages and promote monitoring of 100% juice and alcohol intake, but do not include a definitive, global recommendation to replace all caloric beverages with solid food or low-calorie beverages for the purposes of weight management. Before such recommendations can be made, large, rigorous randomized trials demonstrating a beneficial effect of caloric beverage reduction on body weight over relatively long durations are needed. To date, prior trials have tended to focus exclusively on intake of sugar-sweetened beverages rather than all caloric beverages, and have relied on educational programs, individual behavior change interventions, or provision of low-calorie beverages as the primary intervention strategy [10]. We believe future trials are needed which target reductions in all caloric beverages (with the possible exception of liquid meal replacements), and involve strong, multi-level interventions that include both individual behavior change and environmental interventions.

Several study limitations should be considered. First, low-calorie and high-calorie beverages were classified based on their relation to a natural break-point observed in the distribution of beverage energy densities. Though this classification system is ecologically-relevant, it may have influenced findings to the extent that beverage energy densities were disproportionately represented in the data. This categorization system also did not distinguish between beverages with different nutrient profiles (e.g., soda vs. milk), and a different categorization system would be more appropriate for studies focused on the effects of beverage consumption on diet quality. Second, this study was purely observational in design; therefore, there was no experimental control for potential confounds such as macronutrient content, price, or the behavioral context in which beverages were consumed (e.g., setting, presence of others). Third, this study relied on self-documented dietary intake data, which requires high compliance from participants and is subject to social desirability bias and reactive measurement. In the present study, the likely effect of these issues would have been to bias the pattern of findings toward observing no effect of beverage consumption on solid food or total energy intake. Fourth, participants did not document their intake of water. Although water does not provide energy and generally does not affect solid food intake [18, 25–27], we were unable to separately assess compensation within eating occasions that included water. Finally, this study involved overweight and obese women and findings may not generalize to other groups. There is some evidence that men may compensate for caloric beverages more fully than women [32].

4.1. Conclusions

This study extends prior laboratory and intervention studies by examining dietary compensation for caloric beverages in free-living overweight and obese women. No evidence for dietary compensation was observed within meals or across entire days, and beverages contributed to total energy intake in a near-additive fashion.

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Highlights

- It is unclear if humans reduce solid food intake to offset calories from beverages
- Overweight and obese women completed diet records for seven consecutive days
- Solid food intake was unrelated to caloric beverage intake within meals or days
- Beverages contributed to total energy intake in a near-additive fashion
- No evidence of compensation was found, either within meals or across entire days

Figure 1.

Histogram of the energy densities of reported beverages with Parzen window kernel density estimation. Based on this distribution, beverages with an energy density less than or equal to 0.165 kcal/g were categorized as low-calorie beverages, whereas those above 0.165 kcal/g were categorized as high-calorie beverages. Representative beverages at various energy densities are noted in the key.

A=Diet soda, unsweetened tea/coffee (0.00 – 0.010 kcal/g, 136 observations)

B=Lightly sweetened tea/coffee (0.011 – 0.165 kcal/g, 118 observations)

C=Sweetened tea/coffee, vegetable juice, non-fat milk (0.166 – 0.363 kcal/g, 166 observations)

D=Regular soda, fruit juice, juice drinks, 1% and 2% fat milk (0.364 – 0.599 kcal/g, 348 observations)

E=Whole fat milk, chocolate milk, coffee-based beverages (0.600 – 0.799 kcal/g, 32 observations)

F=Wine, mixed alcoholic beverages (0.800 – 1.219 kcal/g, 37 observations)

G=Fruit smoothies (1.220 – 1.250 kcal/g, 5 observations)

H=Mixed alcoholic beverages (1.251 – 1.714 kcal/g, 5 observations)

I=Mixed alcoholic beverages, coconut milk (1.715 – 2.299 kcal/g, 5 observations)

Figure 2.

Energy intake per eating occasion based on type of beverage consumed. Eating occasions with high-calorie, but not low-calorie, beverages were higher in total energy than those with no reported beverage. Type of beverage consumed was unrelated to energy obtained from solid food. Graph shows covariate-adjusted means $\pm$ SE.

Figure 3.

Daily energy intake by number of high-calorie and low-calorie beverages consumed that day. Each additional high-calorie beverage contributed an additional 147 kcal to total daily energy intake, compared to 39 kcal per additional low-calorie beverage. Graph shows covariate-adjusted means $\pm$ SE.

Table 1

Sample characteristics (N=82).

	M	SD
Age (years)	32.6	8.0
Body mass index (kg/m ²)	32.0	3.9
Moderate and vigorous physical activity (mins/day)	48.0	65.0
Energy intake (kcal/day)	1635.7	406.9
	n	%
Race/ethnicity		
Asian	6	7.3
Black/African-American	32	39.0
Hispanic	15	18.3
Multi-ethnic/Other	5	6.1
Non-Hispanic, White	24	29.3
Marital status		
Single, separated, or divorced	29	35.4
Married or living with partner	53	64.6
Education level		
Less than baccalaureate degree	38	46.3
Baccalaureate degree or higher	44	53.7
Household income (USD)		
\$0–\$29,999	22	26.8
\$30,000–\$59,999	34	41.5
\$60,000–\$89,999	15	18.3
\$90,000 and above	11	13.4

Table 2

Characteristics of eating occasions by type of beverage reported.

	Total	Included a high-calorie beverage ¹	Included a low-calorie beverage ²	No reported beverage
n (%)				
Number of eating occasions	2188	594 (27.1)	217 (9.9)	1377 (62.9)
Consumed as meal	1366	359 (26.3)	128 (9.4)	879 (64.3)
Consumed as snack	639	103 (16.1)	38 (5.9)	498 (77.9)
Consumed as beverage only	183	132 (72.1)	51 (27.9)	0 (0.0)
M (SD)				
Eating occasions per day	4.0 (1.1)	1.1 (1.0)	0.4 (0.7)	2.5 (1.3)
Total energy (kcal)	408.1 (317.4)	501.6 (354.9)	299.4 (266.0)	384.8 (297.6)
Energy from food (kcal)	361.7 (306.3)	335.4 (331.7)	286.5 (268.9)	384.8 (297.6)
Energy from beverages (kcal)	46.4 (104.0)	166.2 (141.3)	12.9 (18.6)	0.0 (0.0)

¹High-calorie beverages had energy densities >0.165 kcal/g.²Low-calorie beverages had energy densities ≤0.165 kcal/g.