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Thirst-drinking, hunger-eating; tight coupling?

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Throughout most of human evolution, hunger was the sensation that prompted feeding, while thirst stimulated drinking. Hunger was primarily linked to energy intake, serving to maintain energy balance (1–3), while thirst was linked to hydration status, ensuring body fluid homeostasis (4). Among primates in the wild, drinking is relatively rare (5); when drinking occurs, it is predominantly peri-prandial i.e., around meals (6–9). Drinking independently of eating was also relatively rare in humans just two decades ago, with approximately 75% of total fluid intake being consumed with meals (10–12). However, recently these patterns have changed. Drinking without food is now an important part of daily routines (13). Further, eating often occurs in the absence of hunger (14–17) and beverages are consumed under conditions of euhydration. Of particular note, beverages have become a significant source of dietary energy (18–20), accounting for ~21% of total daily energy intake (21). Thus, the relationships between thirst, hunger, eating, and drinking have blurred, with uncertain health consequences.

The primary aim of this study was to explore the associations between thirst, hunger, eating, and drinking and to delineate the role of beverages in total fluid and energy intake. Given the widespread consumption of energy-yielding beverages, it was hypothesized that self-reported thirst ratings and drinking would not only be correlated with beverage consumption, but also with hunger and energy intake.

METHODS

Participants

Participants (n=128) were recruited for this observational study through public advertisements and signed an informed consent form approved by the Institutional Review Board of Purdue University. Eligibility criteria included weight stable (<3kg weight change over previous 3 months), male or female, 18–60 years of age, not taking medication reported to affect appetite or body weight, and in good health. Participants had a sedentary lifestyle (PAL = 1.55) (22), determined by self-report to questions about their customary activity level. They were requested to maintain this activity level throughout the study period to avoid the possible confounding effects of strenuous activity on hydration status. The scale was not validated, but was used principally to exclude individuals at the extremes of activity level. Participants were classified as normal weight (BMI ≤ 24.9 kg/m²), overweight (BMI = 25–29.9 kg/m²), or obese (BMI ≥ 30.0 kg/m²) (23) following measurement of height (±0.1 cm) on a wall-mounted stadiometer and body weight (±0.1 kg) on a calibrated scales (model TBF-305; Tanita, Arlington Heights, IL) wearing no shoes and a light gown.

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Appetite and Thirst Ratings

Each participant was requested to record their sensations of hunger and thirst using a Personal Digital Assistant (PalmZire21, Palm, Inc., Sunnyvale, CA) for 7 consecutive days. They were provided with individualized training during baseline. Appetitive ratings were made hourly on a visual analogue scale, during every waking hour. The scales were end-anchored with opposing statements, such as “not at all thirsty” and “as thirsty as I have ever felt”. Due to the lack of recordings during periods of sleep, only responses between 09:00h and 21:00h were assessed (14).

Habitual Food and Beverage Intake

Data on habitual food and beverage intake were collected daily for the same 7-d period by telephone-administered 24-h dietary recalls, administered by trained interviewers using multi-pass software (NDS-R; version 2005; Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN). To aid recall and improve accuracy, participants recorded intake at the time of ingestion and were educated on portion size estimation with food models. Participants with incomplete 7-d recalls (i.e., failed to complete each of the 7 telephone-administered 24-h dietary recalls) were excluded (n=40). However, this group did not differ significantly from the final sample with respect to age, gender, or BMI. Further, the Goldberg cut-off method was used to identify inaccurate reporters (22). Thirty two participants (39%) were identified as under-reporting and were excluded from analysis. This level of under-reporting is comparable to levels reported in the literature (24). Six participants were excluded due to dehydration (mean urinary osmolality >1000mOsm/kg). The final convenience sample included 50 adults (39F; 11M; age 30±11yrs; BMI 26.3±5.9); 27 were normal weight (22.0±1.9kg/m²), 14 were overweight (28.4±1.4kg/m²), and 9 were obese (36.0±4.8kg/m²).

As appetite and thirst ratings were recorded on the hour, food and beverage intake records were compiled into similar hourly intake entries to obtain a comparable unit for analysis. Any food or beverage initially recorded within a given hour was assumed to be consumed within that hour. For any hour when no food or beverage was consumed, intake was recorded as zero. Eating/drinking episodes may have just preceded or followed an appetite recording, but it was assumed this would occur in comparable proportions and so would not lead to a systematic error.

Total fluid intake was defined as any fluid consumed throughout the day in beverage form. This included water, all varieties of tea and coffee, milk and milk-based drinks, fruit drinks/juices, diet and regular soft drinks/soda/energy drinks, meal replacements, and alcohol. Fluid-containing foods, such as soup, were excluded from this definition to allow the focus of the investigation to be on beverages, the principal source of dietary fluids in the US diet (25). Fluids consumed with snacks/meals were defined as peri-prandial drinking, while fluids consumed independent of snacks/meals were defined as drink-only events. Beverages containing energy were defined as energy-yielding beverages i.e., sweetened teas and coffees, milk and milk-based drinks, fruit drinks/juices, soft drinks/soda/energy drinks, meal replacements, and alcohol.

Statistical Analysis

Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS, version 14.0, SPSS Inc., Chicago, IL). Descriptive statistics were calculated for group characteristics and reported as mean ± standard deviation. The relationships between thirst, hunger, and reported energy intake during the same hour were explored using Pearson correlation coefficients, based on averaging all data over days for each person. Fisher Z transformations were used for comparison of Pearson correlation coefficients. Analysis of variance was used to investigate differences between all computed categories. On an individual

level, the relationship between hunger/thirst ratings and energy intake was explored by transforming hunger and thirst ratings into low/normal versus high categories. Individuals were considered hungry when their individual hunger ratings equaled or exceeded one standard deviation above their own mean (14). Thirst was treated similarly. Regression analyses were used to determine the best predictors of energy intake, drinking, hunger, and thirst. For multiple comparisons, the Bonferroni adjustment was applied. A two-tailed level $p < 0.05$ was set as the criterion for significance.

RESULTS AND DISCUSSION

No evidence was obtained indicating that thirst promotes eating and hunger promotes drinking. Thirst was not correlated with energy intake and hunger was not correlated with drinking during the same hour over the 7-d period ($r = 0.08$ and $r = 0.04$, respectively). Further, thirst was not a significant predictor of energy intake and hunger was not a significant predictor of drinking when entered into a linear regression model. Moreover, thirst was not correlated with drinking ($r = 0.03$). Hunger was significantly, albeit moderately, correlated with energy intake during the same hour ($r = 0.30$; $p < 0.05$) and accounted for 14.2% of the variance in total daily energy intake. Using an arbitrary classification of inappropriate ingestive behaviors (i.e., thirsty and hungry, and not drinking or eating; not thirsty and not hungry, but drinking and/or eating; not thirsty but hungry, and drinking but not eating; thirsty but not hungry, and not drinking but eating), participants engaged in inappropriate ingestive events 62% of the time. Participants drank water in response to thirst, in the absence of hunger, 2% of the time, and ate in response to hunger, in the absence of thirst, 68% of the time. The proportion of inappropriate ingestive behaviors did not differ between BMI groups.

These findings raise questions about the fidelity of homeostatic relationships in the current environment as thirst was not predictive of drinking and hunger was only weakly predictive of eating. There are several plausible explanations for these observations. First, changes in the environment or the individual and how the two interact may have degraded the functional relationship between appetitive sensations and intake. The nearly constant availability of foods and beverages and multiple social contexts that encourage eating and drinking in the absence of energy and fluid needs would reduce and confound opportunities to associate eating and drinking with the relief of hunger and thirst. A consequence could be a usurpation of physiological cues to motivate ingestion by environmental cues (26,27).

Second, marked shifts of energy sources have occurred that could also weaken the coupling between appetite and intake. The current low intake of fiber (28,29) and high consumption of energy via beverages (30) are examples that would reduce the satiety value of foods contributing energy. This problem could be exacerbated by the increased consumption of foods with diluted energy content through the substitution of non-nutritive sweeteners for caloric sweeteners and fat replacers for dietary fat. Such manipulations disrupt homeostatic behaviors in rats (31,32) and possibly in humans (33–35).

A third explanation for the weak association between thirst, hunger, and intake may entail the influence of non-homeostatic rewarding properties of foods and beverages. The concept of hedonic hunger has recently been described and proposed as a factor in dysregulated feeding (36). The widespread availability of convenient, inexpensive, highly palatable foods would facilitate the contribution of this mechanism. The concept of hedonic thirst has not been proposed, but may be parallel to hedonic hunger. Properties such as carbonation (37,38), color (39,40), flavor strength (41), palatability (42), sweetness (43), and temperature (43,44) have all been manipulated to encourage drinking that is not necessarily linked to fluid needs.

Another explanation for the lack of association between thirst, hunger, and intake may be more methodological than functional. Current approaches for measurement of appetitive sensations and intake are relatively insensitive (45–47). Patterns of thirst and hunger over the week, compared to isolated ratings just prior to or following meals, were used in this study in an attempt to better capture individual differences in appetitive sensations, but the extent to which this improves measurement accuracy and precision requires further evaluation.

Absolute mean daily thirst ratings were higher than absolute mean daily hunger ratings, with less variance being observed in thirst ratings over the day (Figure 1). Group mean daily thirst was rated at 43 ± 11 , while group mean daily hunger was rated at 31 ± 16 on a 100 unit scale. This higher, stable level of thirst over the day would be more permissive to frequent drinking and may pose a challenge to energy balance as energy-yielding beverages were the main contributor to total fluid intake (55%) (Figure 2). Consumption of energy-yielding beverages is not associated with strong dietary compensation (48), and thus, may lead to an increase in energy intake and weight gain.

Habitual drinking patterns in the present population are consistent with previous findings (10,11), with 75% of fluid intake occurring peri-prandially. There were no significant differences between gender, BMI, or age groups in the type of beverage consumed during peri-prandial and drink-only events (Figure 2). However, mean fluid intake from energy-yielding beverages was higher among overweight/obese individuals than normal weight individuals (61% vs. 49%, respectively). Because energy-yielding beverages contribute uncompensated energy and lead to weight gain, overweight/obese individuals may be at particular risk.

Our study failed to find significant differences in appetitive sensations between gender, BMI, or age groups. However, there was a trend towards higher absolute hunger levels in the obese group relative to the normal weight group ($p=0.07$). This finding warrants further exploration in a larger study population. Additionally, given the overweight/obese group consumed more palatable fluids to meet fluid requirements compared to the normal weight group, possible differential susceptibility to the hedonic properties of beverages demands investigation.

Study limitations include the observational design; thus, no clear conclusions regarding causality can be inferred. Statistical power was also limited, especially for subgroup analyses. Although the telephone administered 24-h dietary recall method used in this study has been validated for collecting dietary information (49), it is not without error. This technique may yield inaccurate estimates of intake, especially in obese individuals. However, the additional step of identifying and excluding inaccurate reporters with the Goldberg cut-off values (22) improves the internal validity and minimizes confounding effects of implausible reports.

CONCLUSION

The failure to reveal significant associations between either thirst or hunger and ingestion of energy-yielding beverages, as well as the absence of strong associations between hunger and eating or thirst and drinking, raises questions about the reliability of these homeostatic relationships in the current environment. While shortcomings in dietary and appetitive assessment tools may be responsible, it is likely that other influences on ingestive behavior overwhelm appetitive sensations. The high palatability of foods and beverages may be of particular importance. The concept of hedonic hunger has recently been described (36). A parallel concept of hedonic thirst, where drinking may be driven more by pleasure and reward than fluid balance warrants consideration. Studying these hedonically-driven behaviors simultaneously may help delineate the causes and consequences of drinking and eating on energy balance and their contribution to overweight/obesity.

References

1. Mayer J. Regulation of energy intake and body weight: the glucostatic and lipostatic hypotheses. *Ann N Y Acad Sci* 1955;63:15–43. [PubMed: 13249313]
2. Friedman MJ, Stricker EM. The physiological psychology of hunger: a physiological perspective. *Psychol Rev* 1976;83:409–431. [PubMed: 1005583]
3. Louise-Sylvestre J, Le Magnen J. A fall in blood glucose levels precedes meal onset in free-living rats. *Neurosci Biobehav Rev* 1980;4:13–15. [PubMed: 6765504]
4. Fitzsimons JT. Thirst. *Physiol Rev* 1972;52:468. [PubMed: 4336576]
5. Schmidt-Nielsen K. The Physiology of Wild Animals. *Proc R Soc Lon B* 1977;199:345–360.
6. Fitzsimons JT, Le Magnen J. Eating as a regulatory control of drinking in the rat. *J Comp Physiol Psychol* 1969;67:273–283. [PubMed: 5787378]
7. Kissileff HR. Food associated drinking in the rat. *J Comp Physiol* 1969;219:1522–1527.
8. Yoburn BC, Cohen PS. Assessment of attack and drinking in White King pigeons on response-independent food schedules. *J Exp Anal Behav* 1979;31:91–101. [PubMed: 571003]
9. Kraly FS. Physiology of drinking elicited by eating. *Psychol Rev* 1984;91:478–490. [PubMed: 6390479]
10. Phillips PA, Rolls BJ, Ledingham JG, Morton JJ. Body fluid changes, thirst and drinking in man during free access to water. *Physiol Behav* 1984;33:357–363. [PubMed: 6514825]
11. De Castro JM. A microregulatory analysis of spontaneous fluid intake by humans: evidence that the amount of liquid ingested and its timing is mainly governed by feeding. *Physio Behav* 1988;43(6): 705–714.
12. Engell D. Interdependency of food and water intake in humans. *Appetite* 1988;10(2):133–141. [PubMed: 3164991]
13. Bisogni CA, Falk LW, Madore E, Blake CE, Jastran M, Sobal J, Devine CM. Dimensions of everyday eating and drinking episodes. *Appetite* 2007;48(2):218–231. [PubMed: 17088011]
14. Mattes RD. Hunger ratings are not a reliable proxy measure of food intake in humans. *Appetite* 1990;15:103–113. [PubMed: 2268136]
15. Hill AJ, Weaver CF, Blundell JE. Food craving, dietary restraint and mood. *Appetite* 1991;17:187–197. [PubMed: 1799281]
16. Wardle J, Steptoe A, Oliver G, Lipsey Z. Stress, dietary restraint and food intake. *J Psychosom Res* 2000;48:195–202. [PubMed: 10719137]
17. Yeomans MR, Blundell JE, Leshem M. Palatability: response to nutritional need or need-free stimulation of appetite? *Br J Nutr* 2004;92:S3–S14. [PubMed: 15384315]
18. Guthrie JF, Morton JF. Food sources of added sweeteners in the diets of Americans. *J Am Diet Assoc* 2000;100:43–51. [PubMed: 10646004]
19. Stroehla BC, Malcoe LH, Velie EM. Dietary sources of nutrients among rural Native American and white children. *J Am Diet Assoc* 2005;105:1908–1916. [PubMed: 16321596]
20. Smith West D, Bursac Z, Quimby D, Prewitt TE, Spatz T, Nash C, Mays G, Eddings K. Self-reported sugar-sweetened beverage intake among college students. *Obesity (Silver Spring)* 2006;14:1825–1831. [PubMed: 17062813]
21. Duffey KJ, Popkin BM. Adults with healthier dietary patterns have healthier beverage patterns. *J Nutr* 2006;136(11):2901–2907. [PubMed: 17056820]
22. Black AE. Critical evaluation of energy intake using the Goldberg cut-off for energy intake: basal metabolic rate. A practical guide to its calculation, use and limitations. *Int J Obes Relat Metab Disord* 2000;24:1119–1130. [PubMed: 11033980]
23. National Institutes of Health [NIH]. Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults – the evidence report. *Obes Res* 1998;51:S51–S209.
24. Huang TK, Roberts SB, Howarth NC, McCrort MA. Effect of screening out implausible energy intake reports on relationships between diet and BMI. *Obes Res* 2005;13:1205–1217. [PubMed: 16076990]
25. Food and Nutrition Board of the Institute of Medicine. Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate. Washington, DC: National Academies Press; 2004. p. D2-D9.

26. Mela DJ. Determinants of food choice: relationships with obesity and weight control. *Obes Res* 2001;9:S249–S255.
27. Hetherington MM. Cues to overeat: psychological factors influencing overconsumption. *Proc Nutr Soc* 2007;66(1):R113–R123.
28. Kranz S, Mitchell DC, Siega-riz AM, Smiciklas-wright H. Dietary fiber intake by American preschoolers is associated with more nutrient-dense diets. *J Am Diet Assoc* 2005;105:221–225. [PubMed: 15668678]
29. Howarth NC, Huang TT, Roberts SB, McCrory MA. Dietary fiber and fat are associated with excess weight in young and middle-aged US adults. *J Am Diet Assoc* 2005;105(9):1365–1372. [PubMed: 16129077]
30. Nielsen SJ, Popkin BM. Changes in beverage intake between 1977 and 2001. *Am J Prev Med* 2004;27:205–210. [PubMed: 15450632]
31. Davidson TL, Swithers SE. Food viscosity influences caloric intake compensation and body weight in rats. *Obes Res* 2005;13(3):537–544. [PubMed: 15833939]
32. Swithers SE, Doerflinger SE, Davidson TL. Consistent relationships between sensory properties of savory snack foods and calories influence food intake in rats. *Int J Obes (London)* 2006;30(11):1685–1692. [PubMed: 16552399]
33. De Graaf C, Hulshof T, Weststrate JA, Hautvast J. Nonabsorbable fat (sucrose polyester) and the regulation of energy intake and body weight. *Am J Physiol Reg Int Comp Physiol* 1996;39:R1386–R1393.
34. Bray GA, Lovejoy JC, Most-Windhauser M, Smith SR, Volaufova J, Denkins Y, De Jonge L, Rood J, Lefevre M, Eldridge AL, Peters JC. A 9-mo randomized clinical trial comparing fat-substituted and fat-reduced diets in healthy obese men: the Ole Study. *Am J Clin Nutr* 2002;76:928–934. [PubMed: 12399262]
35. Lovejoy JC, Bray GA, Lefevre M, Smith SR, Most MM, Denkins YM, Volaufova J, Rood JC, Eldridge AL, Peters JC. Consumption of a controlled low-fat diet containing olestra for 9 months improves health risk factors in conjunction with weight loss in obese men: the Ole' Study. *Int J Obes Relat Metab Disord* 2003;27:1242–1249. [PubMed: 14513073]
36. Lowe MR, Butryn ML. Hedonic hunger: a new dimension of appetite? *Physio Behav* 2007;24(914):R432–R439.
37. Lambert GP, Bleiler TL, Chang RT, Johnson AK, Gisolfi CV. Effects of carbonated and noncarbonated beverages at specific intervals during treadmill running in the heat. *Int J Sport Nutr* 1993;3(2):177–193. [PubMed: 8508195]
38. Guinard JX, Souchart A, Picot M, Rogeaux M, Sieffermann JM. Determinants of the thirst-quenching character of beer. *Appetite* 1998;31(1):101–115. [PubMed: 9716439]
39. Clydesdale FM. Color as a factor in food choice. *Crit Rev Food Sci Nutr* 1993;33(1):83–101. [PubMed: 8424857]
40. Zellner DA, Durlach P. What is refreshing? An investigation of the color and other sensory attributes of refreshing foods and beverages. *Appetite* 2002;39(2):185–186. [PubMed: 12354689]
41. Szlyk PC, Sils IV, Francesconi RP, Hubbard RW, Armstrong LE. Effects of water temperature and flavoring on voluntary dehydration in men. *Physiol Behav* 1989;45(3):639–647. [PubMed: 2756057]
42. Beridot-Therond ME, Arts I, Fantino M, De La Gueronniere V. Short-term effects of the flavour of drinks on ingestive behaviours in man. *Appetite* 1998;31(1):67–81. [PubMed: 9716436]
43. Rolls BJ, Fedoroff IC, Guthrie JF, Laster LJ. Effects of temperature and mode of presentation of juice on hunger, thirst and food intake in humans. *Appetite* 1990;15(3):199–208. [PubMed: 2281950]
44. Boulze D, Montastruc P, Cabanac M. Water intake, pleasure and water temperature in humans. *Physiol Behav* 1983;30(1):97–102. [PubMed: 6836049]
45. Mattes RD, Hollis J, Hayes D, Stunkard AJ. Appetite: measurement and manipulation misgivings. *J Am Diet Assoc* 2005;105:S87–S97. [PubMed: 15867903]
46. Trabulsi J, Schoeller DA. Evaluation of dietary assessment instruments against doubly labeled water, a biomarker of habitual energy intake. *Am J Physiol Endocrinol Metab* 2001;281(5):R891–R899.
47. Hill RJ, Davies PS. The validity of self-reported energy intake as determined using the doubly labelled water technique. *Br J Nutr* 2001;85(4):R415–R430.

48. Mattes RD. Fluid energy-where's the problem? *J Am Diet Assoc* 2006;106(12):1956–1961. [PubMed: 17126624]
49. Krantzler NJ, Mullen BJ, Schutz HG, Grivetti LE, Holden CA, Meiselman HL. Validity of telephone diet recalls and records for assessment of individual food intake. *Am J Clin Nutr* 1982;36:1234–1242. [PubMed: 7148742]

Figure 1.

Figure 1A and 1B: Percent contribution of beverage type to peri-prandial i.e. around meals (A) and drink-only (B) fluid intake, according to gender (males vs. females), BMI (normal weight vs. overweight, including obese) and age (less than 30y vs. greater than 30y).

Figure 2.

Figure 2A and 2B: Correlation between thirst and total daily energy intake (A) and hunger and total daily energy intake (B) across a 7-day period, from 09:00–21:00 (n = 50).