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Interdependency of Food and Water Intake in Humans

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The temporal and quantitative relationship between food and water intake and the effect of fluid restriction on voluntary food intake were studied in 20 male subjects over two 48-h periods. Food intake was limited to specific mealtimes, but subjects could eat as much as they wanted during these times. Drinking was *ad libitum* in one condition, and limited by about 40% of *ad libitum* drinking in the other condition.

Approximately 68% of all drinking occurred when food was available at mealtimes when drinking was *ad libitum*. When fluid intake was limited, subjects voluntarily reduced their food intake. Food acceptability, as measured by hedonic ratings, was not significantly affected by fluid restriction even though food intake was significantly reduced. The intensity rating of thirst was negatively correlated with food intake. Indirect comparisons are drawn with eating and drinking relationships in non-human species.

INTRODUCTION

In temperate environments when food and water are easily accessible, there is a close relationship between eating and drinking in non-human species. Approximately 70% of total 24-h water intake is ingested just before, during, or immediately following meals (Fitzsimons & Le Magnen, 1969; Kissileff, 1969; Normile & Barraco, 1984). In addition, a significant positive correlation has been found between the amount of water ingested with a meal and the size of the meal (Fitzsimons & Le Magnen, 1969; Normile & Barraco, 1984). Furthermore, in non-humans, the amount of drinking with the meal is related to the nutrient content of the meal (e.g. Cizek, 1959; Fitzsimons & Le Magnen, 1969; Richter & Mosier, 1954). Thus, there are temporal, quantitative, and qualitative relationships between eating and drinking under *ad libitum* conditions in non-humans.

The interdependency of food and water intake has also been studied in several species under conditions of deprivation or restriction of food or water. Adolph's classic discussion of this relationship (1947) led to a number of investigations that have shown that animals usually reduce food intake when water intake is restricted (e.g. Adolph, 1947; Bolles, 1969; Finger & Reid, 1952; Kutscher, 1969; Normile & Barraco, 1984), and they usually reduce water intake when food intake is restricted (e.g. Adolph, 1947; Cizek & Nocenti, 1965; Kleitman, 1927). However, this relationship between food and water

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intake is not invariant. An increase in ambient temperature, for example, can result in reduced food intake and enhanced water intake (Anderson *et al.*, 1964), and food deprivation may result in an increase in water intake in some species (Cizek *et al.*, 1966). Results from studies of scheduled deprivation also do not support the generalization that the restriction of one commodity leads to the restriction of the other commodity (Gillette-Bellingham *et al.*, 1986).

Although considerable data exist that demonstrate the interdependency of food and water intake in non-human species, there is a paucity of information on this relationship in humans. The present study was conducted to investigate the relationship between food and water intake in humans. The study was designed specifically to determine the quantitative and temporal relationship between food and fluid intake and to assess the effects of fluid restriction on food acceptability and intake, under conditions of scheduled eating.

Method

Subjects

Twenty male subjects volunteered to participate in this experiment. Subjects had a mean ($\pm SE$) age of 23 ($\pm$0·3) years, body weight of 81·7 ($\pm$3·9) kg, and height of 178 ($\pm$2·6) cm. Subjects were all in good health and were not on any special diets or medications at the time of participation. All subjects were briefed on the procedures and purpose of the study before their participation. Subjects were told that the purpose of the study was to determine the acceptability of various beverages and meals under conditions of restricted and *ad libitum* fluid availability.

Procedures

Each subject participated twice: on one occasion he was in the control *ad libitum* fluid intake (ALF) group, on another he was in the restricted fluid intake (RF) group. The sessions were counterbalanced so that half of the subjects were in the control (ALF) group for their first condition, and half were in the control group for their second condition. During each session half of the subjects participated in the control group and half participated in the RF group. Each session was 48 h and included six consecutive meals.

During the 7 days preceding the experiment, nude body weights for each subject were obtained using an electronic balance ($\pm$10 g) each morning after voiding and before breakfast to determine each subject's baseline weight. As a safety precaution, body weights were monitored three times daily on each test day to obtain a gross estimate of hydrational status.

Subjects ate all of their meals and slept at one location. Dinner was served on day 1; breakfast, lunch and dinner were served on day 2; breakfast and lunch were served on day 3. Between meals, subjects could select from various activities including bicycling, jogging, weight lifting, watching television and playing cards. Each subject kept an activity log during his first 48-h participation, and he duplicated his activity pattern during his second participation.

During ALF and RF trials, food intake was scheduled: breakfast, 0800 hrs; lunch, 1200 hrs; dinner, 1700 hrs. Subjects in both groups were allowed to eat as much as they wanted at mealtimes. A mealtime was defined as the period of time from when a subject began eating or drinking to when a subject terminated eating and drinking and left the dining area. All meals were served when subjects were sitting in a group in a comfortable dining area. All the foods and beverages consumed by subjects were measured on an electronic balance (±1·0 g). Hedonic ratings of all food items were collected using a 9-point hedonic scale (Peryam & Pilgrim, 1957). No between meal snacks were allowed.

Prior to every meal, subjects filled out scales designed to measure the intensity of thirst and hunger. Subjects expressed the intensity of hunger, thirst, and appetite by rating the statements "I feel hungry", "I feel thirsty", and "I have a loss of appetite", on lines of nine points marked "not at all' at one end and "extreme" at the other end.

A variety of beverages were available including water, milk, juice, fruit drink and coffee. When in the control group, subjects were allowed to drink *ad libitum* during and between meals, including overnight. Pitchers of beverages marked with the subjects' identification numbers were available in a refrigerator that was in a room adjacent to where subjects socialized during the study. Canteens were also available for subjects to take with them. Pitchers and canteens were weighed before and after each between meal period to measure beverage intake.

When in the RF group, each subject was given about 250 ml of beverage to drink with his meals; no other fluid was allowed. The amount of fluid available in the RF condition was calculated to be about 40% of the expected *ad libitum* intake. This level of fluid restriction was chosen because similar levels of fluid restriction cause voluntary restriction of food intake in rats (Collier & Levitsky, 1967).

Meals consisted of mostly prepackaged and prepared foods supplemented with some fresh foods. Menus were served in random order. On the average, each meal (excluding beverages) contained approximately 12% protein, 37% carbohydrate, 15% fat, 35% moisture and 1% salt. Carbohydrates contributed about 45% of the total calories, and fat and protein contributed approximately 41 and 14%, respectively.

Results

Temporal Association Between Eating and Drinking

When fluid intake was *ad libitum*, 68·2% (±2·8)% of daily beverage intake was consumed at mealtimes. The pattern of 24-h beverage intake is shown in Figure 1. A repeated measures ANOVA revealed that the beverage intake during meals was significantly greater than the volume of beverage consumed between meal periods $F(1, 19) = 148·5$, $p < 0·001$. There was no significant difference across meals and between meal periods, and there was no interaction.

The overall mean water intake (including water from the food in addition to beverages) at mealtimes was 803·4 (±28·4) ml, which represents 72·5 (±2·7)% of daily water intake. The mean (±*SE*) beverage intake at mealtimes was 653 (±108) ml; between meals, it was 304 (±216) ml. The mean (±*SE*) food intake (excluding water in the food) at mealtimes was 226·8 (±8·8) g.

Quantitative Relationships Between Food and Water Intake

A Pearson product–moment correlation between food (derived from food and beverage) and water (derived from food and beverage) ingested at all six mealtimes was found to be significant, $r = 0·51$, $p < 0·01$. Pearson's correlations between food and

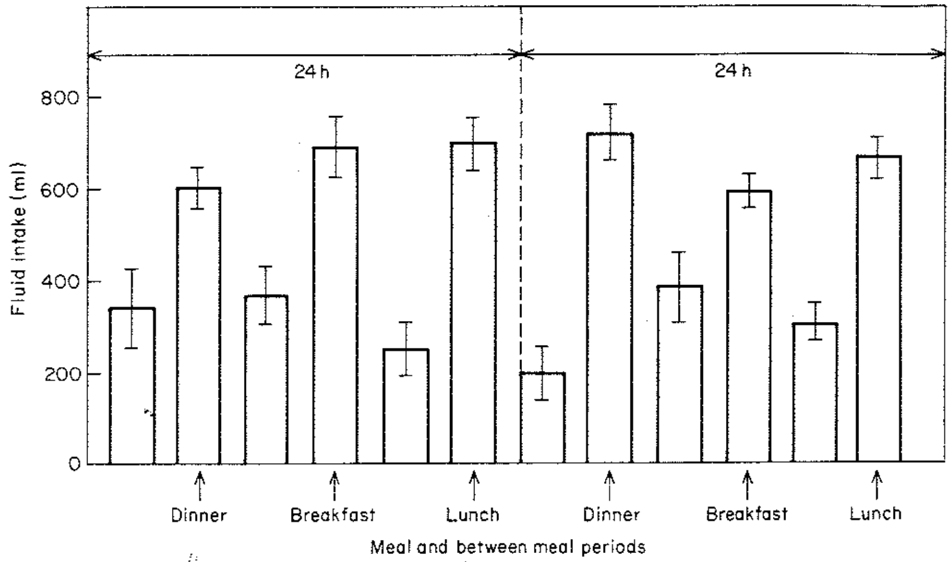

FIGURE 1. Beverage intake during mealtime and between mealtime periods. The period between dinner and breakfast includes overnight.

water intake were found for each subject across six meals. There were significant correlations in 40% of the subjects. Correlations (*r* values) for each subject are shown in Table 1.

A Pearson product–moment correlation between food (including inherent water) and beverage ingested at all six meals was also calculated. The overall correlation was found to be not significant. However, for two of the five mealtimes, there was a significant positive correlation between food and beverage intake: for meal 3 (a lunch), $r = +0.44$, $p < 0.03$; for meal 5 (a breakfast), $r = +0.57$, $p < 0.01$. There was nothing peculiar about these two mealtimes that may explain these correlations.

Food–water ratios were also found for each subject at every meal. The ratios were calculated by dividing the amount of dry food consumed (derived from food and

TABLE 1
Pearson's correlations between food and water intake for each subject across six meals

Subject	*r*	Subject	*r*
1	0·86*	12	0·38
3	0·90**	13	0·78
4	0·47	14	0·32
5	0·37	15	0·48
6	0·68	16	0·56
7	0·80	17	−0·85*
8	0·86*	18	0·81*
9	0·09	19	0·89*
10	0·65	20	0·83*
11	0·32	21	0·93**

Note: * Significant, $p < 0.05$; ** significant, $p < 0.01$.

beverage) by the amount of water drunk and the amount of water found in foods. The mean food–water ratio across meals in the *ad libitum* condition was 0·3 (see Figure 2).

Effect of Fluid Restriction on Voluntary Food Intake and Acceptability

The beverage available to subjects in the restricted fluid condition at each meal was calculated to be about 43% of the beverage consumed in the ALF condition. When subjects were in the restricted fluid intake condition, they voluntarily restricted their food intake by about 37%. A repeated measures ANOVA was used to determine if there was a significant difference in food intake between conditions (ALF vs. RF) and among meals. A significant difference was found between ALF and RF conditions, $F(1, 19) = 72{\cdot}8$, $p < 0{\cdot}001$ and among meals, $F(5, 95) = 6{\cdot}32$, $p < 0{\cdot}001$. There was no significant interaction.

Intake of carbohydrate, protein, and fat were each restricted by approximately 39, 36 and 35%, respectively. However, most foods served were composites of these macronutrients, making selection or restriction of particular nutrients impossible. See Table 2 for a comparison of food intake in control and RF groups. A repeated measures t-test was used to compare the average intake of each nutrient across meals in RF and ALF conditions.

There was no difference in hedonic ratings between RF and ALF groups for the meals as a whole or for individual food items. When in the RF group, subjects rated the food (mean $\pm SE$) 6·9 ($\pm$0·9) on a 9-point range; when in the control group, they rated the food 7·1 ($\pm$0·9). In both conditions the food was "liked moderately" by subjects.

The average food-water ratio in the RF condition was 0·4. The reduction of food intake in the RF condition resulted in the food–water ratio approaching but not meeting the ratio evidenced in the ALF condition. Although the absolute food–water ratio was not maintained in the RF condition, the pattern of ratios observed over the six-meal period was maintained. A repeated measures ANOVA revealed a significant

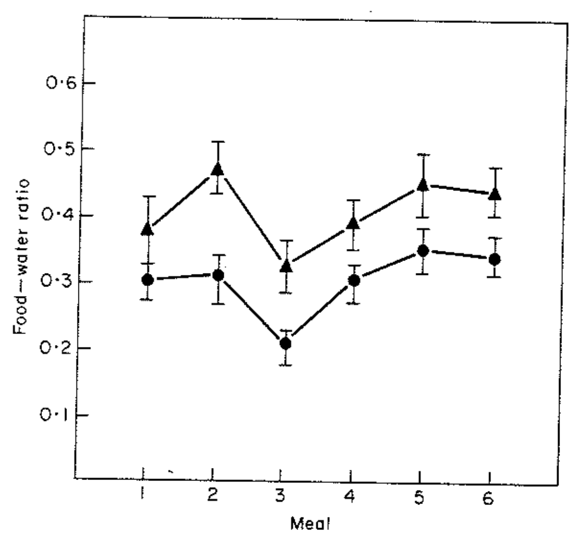

FIGURE 2. Food–water ratios during six consecutive meals for control and fluid restricted conditions. ●, ALF; ▲, RF.

TABLE 2
Comparison of food intake by control and fluid restricted subjects

Intake	Condition		t
	Control	Fluid restricted	
Calories (kcal)	1114 (116)	702 (86)	8·18*
Protein (g)	47 (7)	30 (5)	4·84*
Carbohydrate (g)	130 (11)	79 (9)	4·85*
Fat (g)	50 (6)	32 (5)	5·33*

Note: All t values are significant, $p<0·001$. Standard errors are shown in parentheses.

difference between the RF and ALF conditions, $F(1, 19)=29·31$, $p<0·001$. A significant difference was also found among meals, $F(5, 95)=4·57$, $p<0·001$. Figure 2 illustrates the food–water ratios under RF and ALF conditions for the six meal period.

Although there was a significant difference between control and RF groups in average pre-meal thirst ratings across meals ($t=7·78$, $p<0·001$), there was no significant difference in pre-meal hunger ratings ($t=0·67$, *NS*). Pearson product–moment correlations were calculated between food intake and ratings on "I feel thirsty" and "I feel hungry" scales. There was no significant correlation between "I feel hungry" and food intake for subjects during either control or RF conditions. However, there was an inverse relationship between the judgement of intensity of thirst and the amount of food ingested ($r=-0·47$, $p<0·05$). That is, as the intensity of thirst increased, the amount of food consumed decreased. A significant correlation ($r=0·52$, $p<0·05$) also was found for the intensity of "I feel thirsty" and "I feel a loss of appetite".

DISCUSSION

When food was scheduled at three specific times and fluid intake was *ad libitum* during a 48-h period, approximately 68% of all beverage intake occurred at mealtimes. Rothstein *et al.* (1947) reported that most drinking occurs at mealtimes even when water deficits are accrued between meals. Similarly, Phillips *et al.* (1984) found that subjects drank 68% of their daily beverage consumption with meals under *ad libitum* conditions.

In the present study, beverage intake at mealtimes represented 60% of daily water intake, while water ingested from food and beverage intake at mealtimes accounted for 73% of overall daily water intake (including beverages and water obtained from food). The per cent of daily water intake that was ingested at mealtimes in the present study is also similar to that observed in non-humans. In non-human species, 70% of all fluid intake occurs at mealtimes (Fitzsimmons & Le Magnen, 1969; Kissileff, 1969; Nomile & Barraco, 1984). It is interesting that this similarity exists because in contrast to laboratory animals, humans ingest a significant amount of water through food intake.

There are several explanations for the close temporal relationship between eating and drinking. It is possible that most drinking occurs at mealtimes because drinking reduces aversive sensations evoked by dry or spicy food or enhances sensory stimulation and thus maximizes palatability of foods (Bellisle & Le Magnen, 1981). The present study eliminates this explanation because the acceptability of food as evaluated by hedonic scale ratings was not affected when beverages were limited at mealtimes.

An alternative, but compatible, explanation for the close temporal association between food and fluid intake is an ecological one. In the control condition, fluid was accessible to subjects at all times. However, subjects actually had to make more of an effort to obtain a beverage between mealtimes than during mealtimes because beverages were served with the meals. Thus, less fluid may have been consumed between meals than during meals due to ecological factors. Some authors (e.g., Logan, 1964; Marwine & Collier, 1979; Toates, 1979) have argued that water intake depends on both the state of the body fluids and the availability of water. Although accessibility of fluids was not systematically addressed in this study, the results suggest that relative accessibility of mealtime and between mealtime fluids may have affected *ad libitum* fluid intake.

Other explanations for the close temporal relationship between food and fluid intake include that meal-associated drinking is related to actual physiological states (e.g., Lepkovsky *et al.*, 1957; Deaux *et al.*, 1970; Blair-West & Brook, 1969; Kraly, 1984; Houpt, Note 1), anticipated physiological states (Fitzsimmons, 1972), oropharyngeal factors (Phillips *et al.*, 1984), or physical factors to facilitate chewing and/or swallowing (Kissileff, 1969, 1973). Whether meal associated drinking in humans occurs because of ecological, oropharyngeal, and/or physical factors remains to be assessed in a direct study.

A significant correlation between the amount of food (excluding inherent water) and the amount of water consumed at mealtimes was found in 40% of the subjects in the present study. A significant correlation between food and water intake has been found in obese subjects (Bellisle & Le Magnen, 1981) and in non-human species (e.g., Fitzsimons & Le Magnen, 1969; Nomile & Barraco, 1984). The results of the present study are also similar to results from two primate studies. The variability among subjects is similar to that observed by Natelson & Bonbright (1978), and the food–water ratio found in the *ad libitum* condition is similar to that found by Hamilton (1972).

A significant correlation between food and beverage intake at mealtimes has not been found in other human studies (Adolph & Wills, 1947; in lean subjects, Bellisle & Le Magnen, 1981). The correlations in these human studies are comparable to the correlation that was computed between food (including moisture) and beverage intake that was found to be not significant in the present study. When comparing the relationship between food and water intake in humans and non-humans, differences in diet must be noted. Laboratory animals are usually given dry food to eat, while human subjects are given moist food (e.g. the foods in the present study contained about 35% moisture).

When fluid intake was restricted in the present study, subjects voluntarily reduced their food intake. Subjects ate only about 62% of what their food intake had been when beverage intake was *ad libitum*. Several investigators have found similar levels of voluntary restriction of food intake during water deprivation in non-humans (Bolles, 1969; Finger & Reid, 1952; Verplank & Hayes, 1953).

One explanation of why subjects reduce food intake when water is restricted is that the palatability of food is reduced when drinking is limited. In the present experiment, food acceptability as measured by hedonic ratings was essentially identical in RF and ALF groups, but food intake was significantly less in the RF group. This finding is germane to understanding the contribution of food acceptance to intake. While acceptance ratings are sometimes good predictors of consumption (e.g. Peryam *et al.*, 1960; Seaton & Peryam, 1970; Sidel *et al.*, 1972), it is interesting to note that other factors (such as beverage availability or slight hypohydration) may have more salient effects on food intake.

In conclusion, this study demonstrates that there is a quantitative and temporal relationship between food and water intake in humans. Approximately 68% of all 24-h beverage intake was consumed at mealtimes when fluid intake was *ad libitum*. When beverage intake was restricted, subjects voluntarily restricted their food intake. While hedonic ratings were not affected by fluid restriction and were not good predictors of food intake, ratings of thirst were significantly correlated with the reduction of food intake. Although several explanations for the close association between food and fluid intake were discussed, additional studies are critical to elucidate the mechanisms underlying the relationship.

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