The Time of Day of Food Intake Influences Overall Intake in Humans[1]

John M. de Castro[2]

Department of Psychology, University of Texas at El Paso, El Paso, TX 79968-0553

ABSTRACT Circadian and diurnal rhythms affect food intake, and earlier research has suggested that meal sizes increase, whereas the after-meal intervals and satiety ratios decrease over the day. We hypothesized that the time of day of food intake would be related to total intake such that intake early in the day would tend to reduce overall intake, whereas intake later in the day would tend to increase intake over the entire day. The intakes of 375 male and 492 female free-living individuals, previously obtained via 7-d diet diaries, were reanalyzed. The total and meal intakes of food energy, the amounts of the macronutrients ingested and the density of intake occurring during five 4-h periods (0600–0959, 1000–1359, 1400–1759, 1800–2159 and 2200–0159 h) were identified and related to overall and meal intakes during the entire day. The proportion of intake in the morning was negatively correlated with overall intake ($r = -0.13$, $P < 0.01$), whereas the proportion ingested late in the evening was positively correlated with overall intake ($r = 0.14$, $P < 0.01$). The energy densities of intake during all periods of the day were positively related to overall intake (range, $r = 0.13$–0.23, $P < 0.01$). The results suggest that low energy density intake during any portion of the day can reduce overall intake, that intake in the morning is particularly satiating and can reduce the total amount ingested for the day, and that intake in the late night lacks satiating value and can result in greater overall daily intake. J. Nutr. 134: 104–111, 2004.

KEY WORDS: • *eating* • *circadian rhythms* • *diurnal rhythms* • *meal pattern* • *energy density*

Food intake in humans in their natural environment is affected by a large variety of stimuli including physiologic (1,2), genetic (3–6), rhythmic (7–9), psychological (10–15), social (16–22) and cultural variables (23). Yet, somehow energy intake must be balanced with energy expenditure to maintain body weight. This requires a complex regulatory system that must be able to control intake in the face of a vast array of competing influences many of which are outside the control of the system. We developed a new general model of intake regulation (24) to describe how this might be accomplished for humans in their complex, multivariate, natural environments. It models intake as an integral of the effects of multiple factors acting simultaneously. The model postulates that intake and body size are the net outcome of the influences of a set of compensated factors, such as physiologic processes, which both affect and are affected by intake, and another set of uncompensated factors, such as environmental and psychological variables, which affect but are not affected by intake. Both compensated and uncompensated factor sets have inherited preferred levels and inherited levels of effect.

Computer simulations of this model predict that different intakes and body weights will occur if there are sustained differences in the uncompensated (nonphysiologic) variables even when the physiologic systems are constant. Because the genetically determined physiologic systems may be thought of as relatively constant. the model predicts that changes in intake and body weight must be due to changes in environmental stimuli. This suggests that an understanding of the etiology of the current surge in the incidence of obesity (25,26) may be found by investigating the environmental factors that stimulate intake. This may suggest potential routes for prevention and treatment.

Many behaviors (27,28), including energy intake (7), vary in level and intensity over the course of the day in processes deemed circadian and diurnal rhythms. These rhythms are present in virtually all animals. Studies using the diet diary technique (7) demonstrated that there are substantial and important changes in ingestive behavior that occur over the course of the day in the natural environment. Indeed, 150% more food energy is ingested in the evening relative to the morning. This occurs in conjunction with an increase in meal size as the day progresses (7,9,23,29), producing a modest positive correlation between the time of day and the meal size.

As the meal size increases over the course of the day, the amount of time that the individual waits before eating again, i.e., the after-meal interval, decreases (7,9,23,29). Hence, as the day progresses, the individual eats larger meals but eats again sooner. The satiety ratio is defined as the duration of the following interval divided by the meal size, min/MJ, and gauges the period of satiety produced per unit of food energy ingested. This satiety ratio shows a marked decline over the course of the day and becomes quite low during the late evening. This is true not only for humans (7) in the natural environment, but the pattern can also be discerned in rats in the laboratory (30,31).

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[2] To whom correspondence should be addressed. Present address: Department of Psychology, The University of Texas at El Paso, El Paso, TX 79968-0553. E-mail: jdecastr@utep.edu.

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These findings suggest that during the evening, people become much less satisfied by intake and may be more vulnerable to overeating. On the other hand, eating a relatively larger amount in the morning when the satiating value of food is at a maximum might prove useful for reducing intake. The present research attempted to investigate these hypotheses by studying the relationship between the amounts eaten at various times of the day and the total amount eaten over the course of the entire day. For this purpose, the data on the intakes of free-living individuals that we obtained previously with 7-d diet diaries were reanalyzed (1–13,15–22,32). The total intake occurring during five 4-h periods (0600–0959, 1000–1359, 1400–1759, 1800–2159 and 2200–0159 h) was identified and related to overall and meal intakes during the entire day.

SUBJECTS AND METHODS

Participants. The data were collected from 867 individuals consisting of 375 men and 492 women. They were recruited as participants for a number of earlier studies of intake control in humans (1–13,15–22,32). Both the participants and the experimenter were unaware that the time of day and intake were being studied. The majority of the participants, 536, were paid $30 to participate and also received a detailed nutritional analysis of their intake; 212 subjects participated solely for the nutritional analysis, whereas 119 were undergraduate students who satisfied a course requirement. The participants had a mean (±SD) age of 36.3 ± 13.8 y; weight and height were 69.5 ± 15.8 kg and 1.68 ± 0.10 m, respectively, and BMI was 24.5 ± 4.3 kg/m^2. Individuals were excluded if they were actively dieting, were pregnant or lactating, on chronic medication or alcoholic as ascertained using a demographic questionnaire. The study was approved by the Georgia State University Institutional Review Board.

Procedure. For a detailed review of the method, reliability and validity of the diet-diary procedure see de Castro (33,34). The participants were given a small (8 × 18 cm) pocket-sized diary and were instructed to record in as detailed a manner as possible every item that they either ate or drank, the time they ate it, the amount they consumed, how the food was prepared, the number of other people eating with them and self-ratings of their hunger, thirst, anxiety, depression and the attractiveness of the food. The participants initially recorded this information for a day and reviewed the records with the experimenter. They then recorded their intake for seven consecutive days. They were contacted subsequently to clarify any ambiguities or missing data. Two individuals who ate with the participant were contacted and asked to verify the reported intake. In some cases, there was difficulty in recalling exactly what was eaten. However, in no case was the diary report contradicted in either the nature or the amount (33,34).

Data analysis. The foods reported in the diaries were assigned codes from a computer file of >3500 food items by an experienced dietitian. The coder was unaware of the experimental hypotheses and the participants' characteristics and did not interact directly with the participants. Total daily intakes of food energy were calculated by summing the contributions of the individual items. Meals were identified and the compositions of the individual items composing the meal were summed. For a reported intake to be classified as an individual meal, it had to contain at least 209 kJ, or more stringently 418 or 837kJ. It also had to be separated in time from the preceding and following intakes by at least 15 min. More stringent definitions of 45 and 90 min were also employed. Five different definitions of a meal were used combining these minimum criteria, 15 min and 209 kJ, 45 min and 209 kJ, 45 min and 418 kJ, 45 min and 837 kJ, and 90 min and 209 kJ. Although quantitative differences were apparent among the results obtained for the five meal definitions, the patterns of the results did not differ. Thus only the minimum 209 kJ and 45 min definition is presented as representative.

For each identified meal, we calculated the meal size of food energy, carbohydrate, fat, protein, and alcohol, duration of the meal, rate of intake, duration of the intervals prior to and after the meal, and the duration of the after meal interval divided by the meal size (satiety ratio). To investigate the influence of time of day of intake on overall intake, the total and meal amounts of nutrients ingested during five periods during the day (0600 to 0959, 1000 to 1359, 1400 to 1759, 1800 to 2159 and 2200–0159 h) were calculated. These intervals were selected because they capture periods of peak intake and are bounded by periods of low intake as observed in earlier studies of North American subjects (7). The absolute amounts of total food energy, carbohydrate, fat, protein and alcohol ingested during these periods were calculated. In addition, the percentage of the total daily intake of each nutrient ingested during each period was calculated. Dietary energy densities (MJ/g) were also calculated for all periods as the total food energy ingested (MJ) divided by the total weight (g) of everything ingested during the period. A second energy density measure was calculated similarly except that drinks were removed before calculation. This second calculation provides a measure of the density of foods only. Repeated-measures ANOVA was used to compare the intake variables among the five periods. Differences between each pair of the five periods were assessed with a t test applying the Bonferroni correction (35) for multiple comparisons ($\alpha_{bon} = 0.05$).

To assess the relationship between time of day of intake and overall intake, correlations were calculated between the amounts and proportions of intake ingested during each period and the total amounts ingested over the entire day. Directly correlating the amount ingested during a period with the total amount eaten over the day would produce a spurious positive correlation because the variables covary as the amount eaten during any particular period contributes to overall intake. To correct for this problem, the proportion of the day's intake that was eaten during each period was used instead of the absolute amounts. These proportions were then correlated with the absolute amounts ingested over the entire day for each subject individually. Mean correlations were then calculated over all participants and for men and women separately and compared with zero using a t test (36).

Because there is a tendency for diary recording to produce either underreporting or reduced intake, the correlation analysis was repeated excluding all subjects whose reported intake was <110% of their estimated basal metabolic rate. This criterion is commonly used as a reasonable cut-off value for identifying underreporting (37,38). Another potential alternative interpretation of the correlations is as an artifact of the pattern of intake on weekdays vs. weekends. During weekdays, intake tends to be smaller and earlier in the day compared with weekends. Intermixing days of relatively early and small intake (weekdays) with days of relatively late and large intake (weekends) could produce the pattern of results observed for the correlations. To investigate this possibility, the analysis was repeated but only for weekdays (Monday through Thursday) and again for weekends (Friday through Sunday).

As another method of assessing the relationship between time of day of intake and overall intake, days when intake during the morning (0600 to 1159), afternoon (1200 to 1759) or evening (1800 to 0200) were above the mean for each individual participant were separated from days of below the mean intake for the same participant. These below vs. above the mean days were then compared for overall intakes and the meal patterns with repeated-measures ANOVA and correlated t tests. Separate analyses were conducted for men and women and for weekdays (Mondays through Thursday) and weekend days (Friday through Sunday).

RESULTS

Total intake over the day. The total food energy ingested differed among the five time periods throughout the day [$F(4,3464) = 832.4$, $P < 0.01$] with all 4-h periods differing significantly from all other periods (t tests, $P < 0.05$ (**Fig. 1**). These intake differences among the 4-h periods were the same for the macronutrients individually. Hence, it appears that there were considerable differences among the intakes of food during different periods of the day with peaks during the 1000–1400 and 1800–2200 h periods.

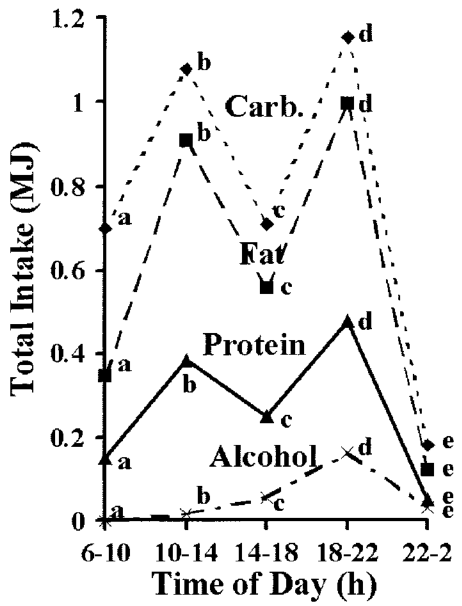

FIGURE 1 Total energy intakes by subjects as carbohydrate, fat, protein and alcohol during five 4-h periods of the day as reported in 7-d diet diaries. Values are means, $n = 867$; pooled SEM = 0.004. Means without a common letter differ, $P < 0.05$.

The energy density of overall intake (**Fig. 2**) differed over the five time periods [$F(4,3464) = 21.1$, $P < 0.01$] due solely to the fact that the density of intake during the first period (0600–0959) was significantly smaller than all of the other periods. Dietary energy density during all other periods did not differ from any other period. When density was calculated after removing beverage energy intake, however, a different pattern emerged. There was a significant change over the day [$F(4,3464) = 40.0$, $P < 0.01$], but the density of intake during the first period (0600–0959) was significantly higher than during the second (1000–1359), third (1400–1759) and fourth (1800–2159) periods, whereas the density during the fifth period (2200–0159) was significantly higher than all of the other periods. This indicates that the low overall energy density of early intake resulted from relatively high beverage intake during this early period. In fact, the energy density of food ingested in the morning was higher than the rest of the day, except the late night period. It also indicates that the late night period was when the highest density foods were eaten.

Meal intake over the day. The mean meal sizes of food energy (**Fig. 3**) differed among the periods [$F(4,3464) = 131.0$, $P < 0.01$] with meal sizes during all five of 4-h periods significantly different from all other periods except that the second period (1000–1359) did not differ from the third period (1400–1759). These meal size differences among the 4-h periods were the same for the macronutrients individually (**Fig. 4**) except that the meal sizes of both fat and alcohol during all five of the 4-h periods differed significantly from all other periods. The changes in meal size occurred due to an increase in the time spent eating (duration of the meal) [$F(4,3464) = 17.6$, $P < 0.01$] and not to the rate of intake [$F(4,3464) = 0.3$, $P > 0.50$] (**Fig. 5**).

A very interesting aspect of the meal pattern over the day was that although the meal size increased over the day up until 2200 h (Fig. 3), the time until the next meal (after meal interval) actually decreased over the same period (**Fig. 6**). The after-meal interval decreased over the five 4-h periods [$F(4,3464) = 390.0$, $P < 0.01$] with after-meal intervals during all five of the 4-h periods significantly different from all other periods except that the after-meal intervals during the second period (1000–1359) were slightly longer than during the first period (0600–0959). Hence, even though more food was eaten in the meals as the day progressed, the individuals chose to eat again sooner. This can be captured in the satiety ratio, which provides a measure of how long the individual will wait until he/she eats again per amount eaten in the meal. The satiety ratios (**Fig. 7**) decreased over the day [$F(4,3464)$

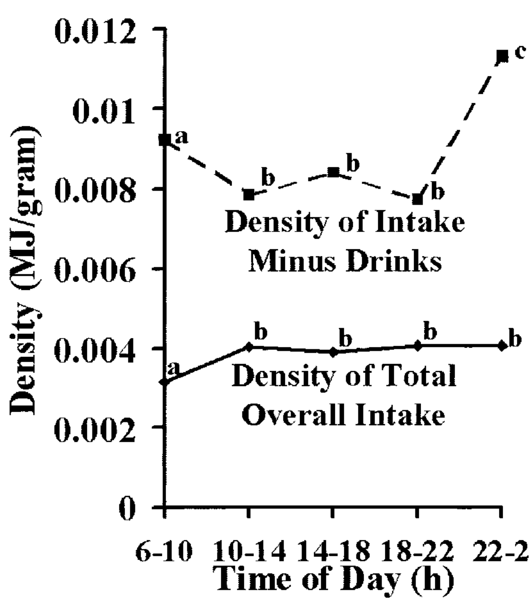

FIGURE 2 Energy density of total intake and intake excluding drinks by subjects during five 4-h periods of the day as reported in 7-d diet diaries. Values are means, $n = 867$; pooled SEM = 0.001. Means without a common letter differ, $P < 0.05$.

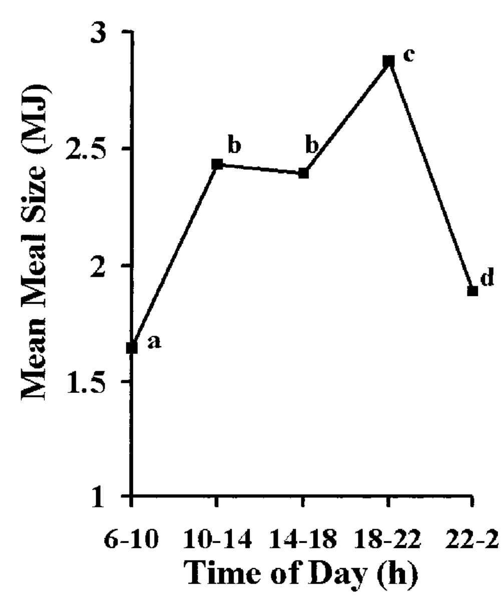

FIGURE 3 Energy contents of meals of subjects during five 4-h periods of the day as reported in 7-d diet diaries. Values are means, $n = 867$; pooled SEM = 0.002. Means without a common letter differ, $P < 0.05$.

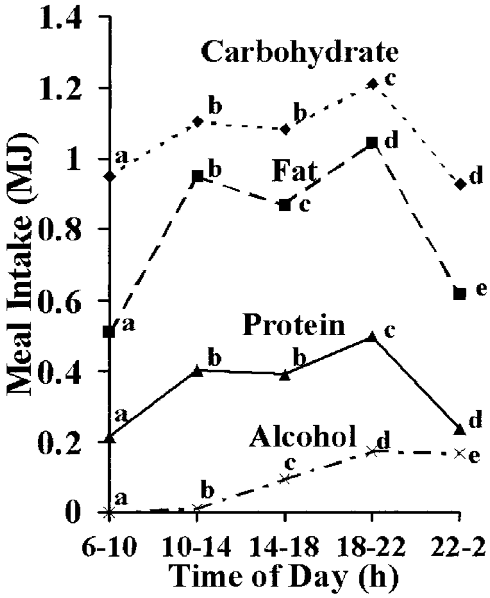

FIGURE 4 Intakes per meal of energy as carbohydrate, fat, protein and alcohol of humans during five 4-h periods of the day as reported in 7-d diet diaries. Values are means, $n = 867$; pooled SEM = 0.001. Means without a common letter differ, $P < 0.05$.

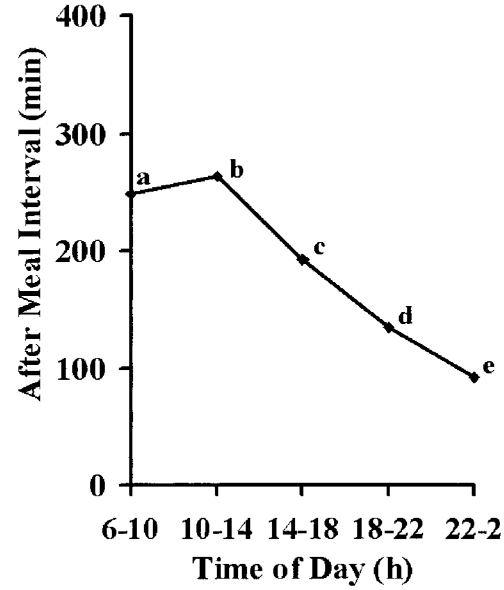

FIGURE 6 After meal-intervals of humans during five 4-h periods of the day as reported in 7-d diet diaries. Values are means, $n = 867$; pooled SEM = 2.45. Means without a common letter differ, $P < 0.05$.

= 144.3, $P < 0.01$]; during the first period (0600–0959), they were significantly higher than the other four periods, and periods two and three were higher than either periods four and five. Hence, the satiation produced by the meal decreased markedly over the day, such that eating during the morning produced the greatest satiety, whereas eating in the evening produced the least.

Correlations between intake during the day and overall intake. The analysis of the meal pattern and satiety ratios presented above suggests that eating a large amount in the morning may result in lower total daily intake, whereas eating a large amount at night might result in higher total intake. To assess this question, correlations were calculated between the proportion of the day's intake ingested during each of the five periods and the day's total intake. The correlations were small in magnitude and the same pattern appeared to be present for both genders (**Fig. 8**). The most striking aspect of these correlations was their systematic change over the day. In the morning, the correlations were significantly negative, suggesting that ingesting a high proportion of the daily intake in the morning was associated with lower overall intake. On the other hand, the correlations for the late evening were positive, suggesting that ingesting a high proportion of daily intake in

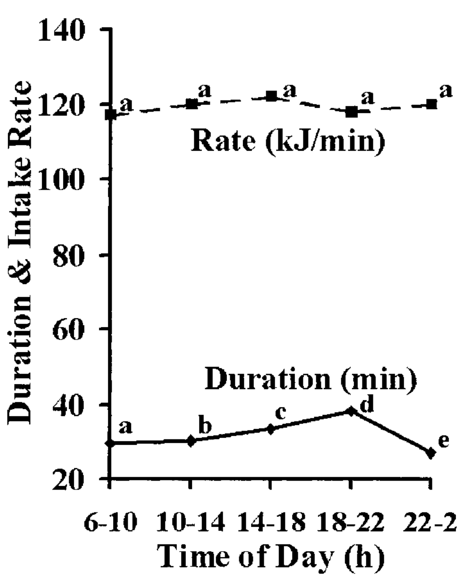

FIGURE 5 Meal duration and rate of energy intake of subjects during five 4-h periods of the day as reported in 7-d diet diaries. Values are means, $n = 867$; pooled SEM = 0.212 (rate); 0.926 (duration). Means without a common letter differ, $P < 0.05$.

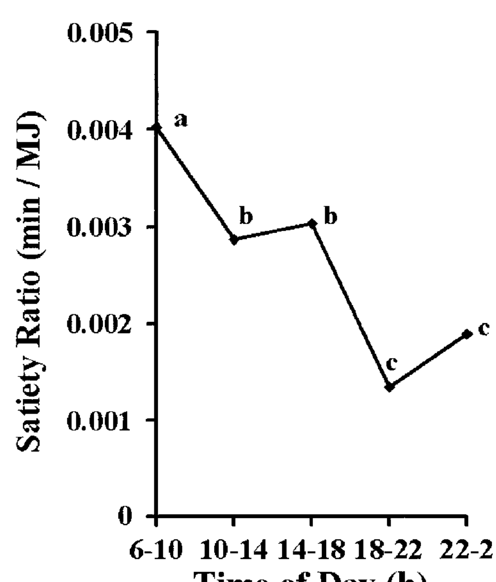

FIGURE 7 Satiety ratios of humans during five 4-h periods of the day as reported in 7-d diet diaries. Values are means, $n = 867$; pooled SEM = 0.00007. Means without a common letter differ, $P < 0.05$.

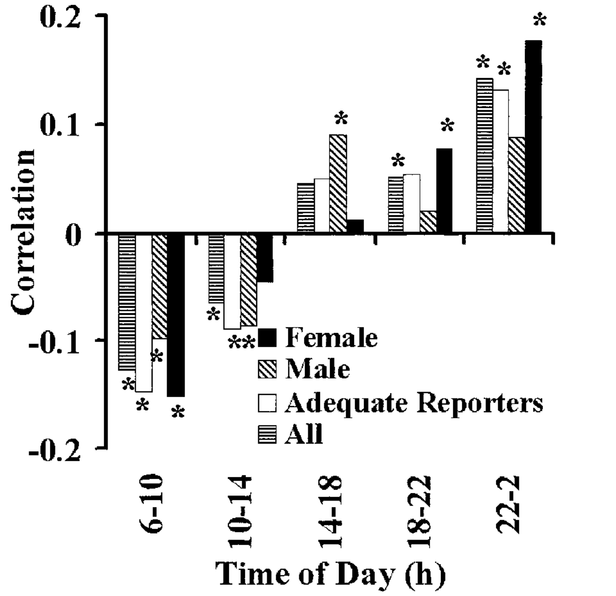

FIGURE 8 Correlations between the proportions of food energy ingested by humans self-reported in 7-d diet diaries during each of the five time periods and the total amount of energy ingested during the day for all subjects, for subjects identified as adequate reporters, for men only and for women only. *Different from zero, $P < 0.01$.

the late evening was associated with higher overall intake. There were 586 subjects who met the criterion for adequate reporting. The pattern of the correlations over the five time periods (Fig. 8; open bars) was the same for this subsample as it was for the entire sample. This suggests that the pattern of correlations over the day occurs regardless of underreporting. The pattern of correlations was the same for weekdays and weekend days as it was for the entire week (**Fig. 9**), suggesting that the pattern is not an artifact of the intermixing of weekdays and weekend days.

The dietary energy density during the five time periods was significantly positively correlated with the total daily intake, regardless of time period and whether density was calculated with or without the inclusion of drinks. The correlations were 0.131, 0.201, 0.156, 0.232 and 0.137 for overall energy density and 0.112, 0.144, 0.174, 0.18 and 0.155 for energy density calculated without the inclusion of drinks ($P < 0.01$) for the five periods, respectively.

Days above or below the mean proportionate intake for the morning, afternoon or evening. The correlation analysis suggests that high proportional intake during the morning is associated with low overall daily intake, whereas high proportional intake during the evening is associated with high overall intake. To further investigate this idea, the days on which individual participants ate a proportion of their intake for the morning, afternoon and evening periods that was below their individual mean proportional intake for that period were separated from days on which they were above the mean (**Table 1**). A significant interaction was present between the influence of being below or above the mean during the morning, afternoon, and evening [$F(2, 3464) = 27.76$, $P < 0.01$]. On days when the proportion of intake was below the mean for the morning, the participants ate significantly more over the entire day than they did on days when they were above the mean. In addition, on days when the proportion of intake was below the mean for the evening, the participants ate significantly less over the entire day than they did on days when they were above the mean. The same pattern of results were present when the analysis was performed separately for men and women. Hence, eating a large proportion of intake in the morning was associated with eating less overall, whereas eating a large proportion of intake in the evening was associated with eating more.

This analysis was repeated with each macronutrient as the dependent variable. The amounts of each macronutrient ingested were calculated for days on which individual participants ate a proportion of their total intake for the morning, afternoon and evening periods below and above their individual mean proportional intake for that period (Table 1). There was no significant effect for carbohydrate. But there was a significant interaction for both fat [$F(2, 3464) = 19.24$, $P < 0.01$] and protein [$F(2, 3464) = 32.99$, $P < 0.01$]. On days when intake in the morning was higher than the mean, the participants ate less total fat and protein than on days when they ate less than the mean. In addition, on days when intake in the evening was higher than the mean, the participants ate more total protein than on days when they ate less than the mean. Hence, the same pattern of results seen for total food energy was apparent for fat and protein, with high intake in the morning associated with low overall intake over the entire day and high intake in the evening associated with high overall intake over the entire day.

The meal characteristics were calculated for days when individuals' intakes were below or above their mean intakes in the morning, afternoon and evening (Table 1). The decrease in overall intake on days when they ate more in the morning than their mean resulted from smaller mean meal sizes consisting of less fat, protein and alcohol consumed earlier in the day. There were no significant differences between the below and above the mean days for meal frequency, the number of people present and the hunger and palatability ratings. Hence, the differences in intake were due to differences in meal sizes

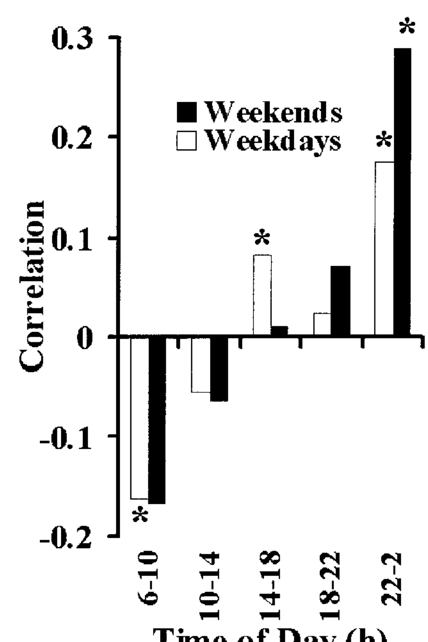

FIGURE 9 Correlations between the proportions of food energy ingested by humans self-reported in 7-d diet diaries during each of the five time periods and the total amount of energy ingested during the day for intake during weekdays only and intake during the weekends only. *Different from zero, $P < 0.01$.

TABLE 1

Mean intakes on days when the proportion of intake was below and above the mean for individual subjects for the morning, afternoon and evening periods[1]

	Morning (0600–1159 h)		Afternoon (1200–1759 h)		Evening (1800–0200 h)	
	Below	Above	Below	Above	Below	Above
Total energy intake, *kJ/d*	8523 ± 95	8150 ± 96*	8355 ± 92	8309 ± 94	8179 ± 90	8485 ± 97
Carbohydrate, *kJ/d*	3925 ± 46	3883 ± 54	3891 ± 46	3887 ± 46	3870 ± 46	3920 ± 50
Fat, *kJ/d*	3075 ± 42	2908 ± 43*	2979 ± 41	2996 ± 42	2925 ± 43	3037 ± 45
Protein, *kJ/d*	1364 ± 17	1287 ± 17*	1339 ± 17	1335 ± 16	1301 ± 16	1364 ± 17
Total meal energy, *kJ*	2506 ± 29	2372 ± 27*	2448 ± 30	2435 ± 29	2389 ± 30	2485 ± 28
Carbohydrate, *kJ*	1121 ± 13	1096 ± 17	1105 ± 12	1104 ± 14	1100 ± 13	1113 ± 13
Fat, *kJ*	895 ± 14	841 ± 13*	866 ± 14	870 ± 12	849 ± 13	883 ± 12
Protein, *kJ*	397 ± 5	372 ± 5*	385 ± 4	389 ± 5	377 ± 4	393 ± 5
Alcohol, *kJ*	92 ± 6	63 ± 4*	92 ± 6	71 ± 5*	63 ± 5	96 ± 8
Total energy density, *kJ/g*	4.56 ± 0.04	4.57 ± 0.03	4.56 ± 0.04	4.55 ± 0.05	4.57 ± 0.04	4.55 ± 0.04
Energy density without drinks, *kJ/g*	9.79 ± 0.13	9.54 ± 0.13	9.58 ± 0.08	9.75 ± 0.11	9.66 ± 0.13	9.71 ± 0.12
Frequency, *meals/d*	3.54 ± 0.03	3.6 ± 0.03	3.58 ± 0.03	3.56 ± 0.03	3.56 ± 0.03	3.57 ± 0.03
Beginning time,[2] *h*	14.77 ± 0.05	14.03 ± 0.04*	14.48 ± 0.05	14.4 ± 0.05	14.12 ± 0.05	14.78 ± 0.05
People also eating, *n*	1.65 ± 0.04	1.62 ± 0.05	1.63 ± 0.04	1.66 ± 0.05	1.65 ± 0.05	1.67 ± 0.04
Hunger rating[3]	5 ± 0.02	4.96 ± .03	4.99 ± 0.02	4.97 ± 0.02	4.95 ± 0.02	5.01 ± 0.02
Palatability rating[3]	5.23 ± 0.03	5.22 ± 0.03	5.24 ± 0.03	5.21 ± 0.03	5.2 ± 0.03	5.25 ± 0.03

[1] Values are means ± SEM, $n = 867$. * Different from below the mean, $P < 0.01$ (t test).
[2] Military time in decimal format.
[3] Before eating. Scale: 1 to 7.

and not to differences in eating frequency, social facilitation, hunger or palatability.

DISCUSSION

The diet-diary technique, used in the present study, is a self-report methodology that is not absolutely accurate. However, there is evidence to suggest that it is reasonably reliable and valid [(39–43); see (33,34) for review], although it appears to underestimate intake (44–47). It is important to understand how the inaccuracy might affect the analysis being performed. Underestimation influences the magnitude of the estimates of intake. Thus, in the present analysis, not only were the absolute values analyzed but also the proportions of intake that are magnitude independent. Hence, because the intake proportions showed effects in the present analysis, recording errors are unlikely to be responsible for the observed relationships. In addition, underestimation may differ systematically between subjects such that certain participants (e.g., overweight) might tend to underestimate more than others. However, the results were significant for the proportions of intake calculated individually for each subject. This form of analysis corrects for the overall and individual underestimated level of intake. Hence, a differential underestimation could not account for the present results. Unsystematic, random, errors of measurement likely remain; however, these should obfuscate relationships, not produce them. The fact that significant relationships were found with a technique that includes considerable error suggests that the effects reported may actually be underestimated and that the influence of the time of day of intake was in fact considerably stronger than indicated by the reported results.

In agreement with earlier work (7,9), the present study found that intake by free-living humans varies considerably over the day. The amount of energy ingested appears to increase over the day with peaks during the lunch and dinner periods. This is not due to an increase in energy density, except possibly late at night, but occurs as a result of increasingly larger meals of longer duration over the day. Also, the larger meal sizes over the day were accompanied by smaller amounts of time elapsing before the next meal, producing a precipitous decline in the satiety ratio. Hence, over the day, intake increases, but the satiating effect of intake decreases.

The present results suggest that intake during different periods throughout the day may have differing effects on overall intake. If indeed intake in the morning is particularly satiating, then eating a large amount during the morning may reduce intake over the entire day. On the other hand, if intake in the late evening is particularly low in satiating value, then eating a large amount during this period may increase intake over the entire day. The correlations between the proportions of intake during various times through the day support this notion. The larger the proportion of total intake in the morning, the smaller the overall intake, whereas the larger the proportion of total intake in the late evening, the larger the total intake. This was true for both men and women, for adequately reporting subjects and for weekday and weekend periods, indicating that the reported relationships were not spurious. It should be noted that the magnitudes of the correlations were small. This suggests that daily intake is affected by a number of variables and that the time of day is a significant factor, but only one of many.

The notion that morning intake is associated with reduced overall intake, whereas late evening intake is associated with increased overall intake, was further supported by the analysis of high vs. low proportional intake days. We found that when individual subjects ate a larger than the mean proportion of their total intake during the morning, they ate significantly less over the entire day. Conversely, when these same subjects ate a high proportion of their total intake during the evening, they ate significantly more over the entire day. This result adds to the correlation analysis results and the satiety ratio results in suggesting that intake during the morning may suppress intake during the remainder of the day, whereas intake late at night may supplement and thereby increase overall daily intakes.

It is quite clear from the analyses that the higher the energy density of the foods ingested, the more that tends to be eaten, as others have reported (48–50). But, the present results also demonstrate that this occurs regardless of the time of day. In previous work, it was demonstrated that when identical twins differed in their daily intake, it was associated with differences in their dietary energy density (51). It should be noted, however, that diet energy density differences were not related to body weight or BMI differences in these twin pairs. Indeed, dietary energy density was not correlated with body weight or BMI using an extensive database of over 800 individuals (32). This suggests that dietary energy density affects short-term intake, but may not have long-term effects on body weight and fatness. Nevertheless, the present study, along with these earlier studies, strongly suggests that a reduction in the energy density of the diet is associated with a reduction in total intake over the day regardless of the time of day of intake.

In essence the present analysis suggests that intake in the morning of low density foods is satiating and can reduce the amount ingested over the rest of the day to such an extent that the total amount ingested for the day is less. It also suggests that low density intake during any portion of the day could reduce overall intake. Finally, it suggests that intake in the late night time period may supplement the earlier intake to the extent that it results in greater overall daily intake. This evidence is strictly correlative in nature; thus, it is not clear that there is a causal connection present. It remains for future research to establish whether the active manipulation of the time of day of intake can produce changes in overall daily intake.

It is interesting to speculate that there may be a connection between the results obtained and the current epidemic of obesity (25,26). Intake late in the day does not appear to be particularly satiating. Earlier in our evolutionary history, the advent of night greatly restricted activity. In modern times, however, the widespread use of artificial lighting has allowed people to remain active and eating late into the night. Could it be that obesity in the modern world results in part from the extension of the active period into the night when satiety mechanisms appear to be weak? The present results that intake in the late night period are associated with higher overall daily intake supports this speculation. If this is true, then a dietary regimen that encourages the ingestion of relatively large amounts of food in the morning and restricts intake during the evening might reduce overall intake and serve as a treatment or a preventative measure for obesity.

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