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The time of day and the proportions of macronutrients eaten are related to total daily food intake

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Intake in the morning is particularly satiating and associated with lower total amounts ingested for the day while intake at night is associated with greater overall daily intake. But, the influence of carbohydrates, fats or proteins ingested at various times of the day is unknown. The intakes of 375 male and 492 female free-living individuals that were acquired with 7 d diet-diary reports were reanalysed. The intakes of carbohydrates, fats and proteins, and the density of intake occurring during three 6 h periods (06.00 to 11.59 hours (morning), 12.00 to 17.59 hours (afternoon) and 18.00 to 23.59 hours (evening)) were identified and related to overall daily and meal intakes. Energy density of intake during all periods was found to be positively related to overall intake. When the proportion of daily carbohydrate ingested in the morning was high, less total food energy and carbohydrate were ingested over the entire day. When the proportion of daily fat ingested in the morning was high, less total food energy and carbohydrate and fat were ingested over the entire day. When the proportion of daily protein ingested in the morning was high, less protein was ingested over the entire day. Conversely, when intake was relatively high in the evening of either total food energy, carbohydrate or fat, then overall daily energy intakes tended to be higher. The results suggest that the morning intake association with reduced total intake is macronutrient specific, with morning carbohydrate, fat and protein intake associated with reduced daily carbohydrate, fat and protein intake, respectively.

Eating: Circadian rhythms: Diurnal rhythms: Energy density: Breakfast

There are substantial and important changes in ingestive behaviour that occur over the course of the day in the natural environment[1]. Indeed, 150 % more food energy is ingested in the evening relative to the morning. As the day progresses the individual eats larger meals but eats again sooner[1–4], indicating a marked decline in the satiating properties of food over the course of the day. This suggests that eating in the morning might produce greater satiety than eating later in the day. Indeed, in human subjects, eating a large proportion of intake in the morning is associated with lower overall intake while eating a high proportion of intake in the evening is associated with higher overall intake[5].

In prior research, food intake during various portions of the day was characterised simply by its energy content and dietary energy density[5]. There is evidence, however, that the various macronutrients may have different influences on intake[6–7]. Indeed, the 2 d delayed feedback from nutrients ingested during a day appears to be macronutrient specific[8]. Carbohydrate appears to influence subsequent carbohydrate intake to a far greater extent than the intakes of fat or protein[8]. Similarly, fat intakes appear to influence subsequent fat intakes and protein intakes appear to influence subsequent protein intakes to a greater extent than the intakes of the other macronutrients[8]. Also, the types of foods eaten in the morning may make a difference. Individuals who ate high-carbohydrate breakfasts tended to have lower BMI than individuals who skipped breakfast or ate a high-protein breakfast[9] and children with greater intakes of ready-to-eat breakfast cereals tended to have lower body weights[10] and lower fat intakes[11].

Hence it is important to look at the consumption of varying amounts of carbohydrates, fats and proteins at different times of the day and their relationships with overall and macronutrient intakes. The present research attempted to investigate this issue by reanalysing the data on the intakes of free-living individuals that we have acquired with 7 d diet diaries[1,3,5,6,8,12–23]. The total intake occurring during the morning, afternoon and evening was identified and related to overall food energy and macronutrient intakes during the entire day.

Materials and methods

Participants

The data were collected from 867 individuals consisting of 375 males and 492 females. They were recruited as participants for a number of prior studies of intake control in human subjects[1,3,5,6,8,12–23]. Obviously, both the participants and the experimenter were unaware that the time of day and intake was being studied. The majority of the participants, 536, were paid $30 to participate and also received a detailed nutritional analysis of their intake although 212 participated solely for the nutritional analysis, while 119 were undergraduate students who satisfied a course requirement. The participants had a mean age of 36·3 (SD 13·8) years,

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weight of 69·5 (SD 15·8) kg and height of 1·68 (SD 0·10) m and had a mean BMI of 24·5 (SD 4·3) kg/m^2. In order to participate the individuals could not be actively dieting, pregnant or lactating, on chronic medication, or alcoholic as ascertained with 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[24,25]. 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 and how the food was prepared. The participants initially recorded this information for a practice day and reviewed the records with the experimenter. They then recorded their intake for 7 consecutive days. Afterwards they were contacted to clarify any ambiguities or missing data. In most cases, two individuals who ate with the participant were contacted and asked to verify the reported intake. In some cases, difficulty was encountered in remembering exactly what was eaten. However, in no case was the diary report contradicted in either the nature or the amount[24,25].

Data analysis

An experienced dietitian assigned codes to all foods reported in the diaries using a computer file of over 3500 food items (for more information regarding the coding procedure and database, see de Castro[24,25]). 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, carbohydrate, fat and protein were calculated by summing the contributions of the individual items. To investigate the influence of morning, afternoon and evening intake on overall intake the total amounts of food energy, carbohydrate, fat and protein ingested during three periods during the day: 06.00 to 11.59 hours (morning); 12.00 to 17.59 hours (afternoon) and 18.00 to 23.59 hours (evening) 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, providing a measure of the density of foods only.

All analyses were performed within subjects. That is, each participant's intake during one period was compared with the same participant's intake during another period. As discussed by de Castro[18], this is the most appropriate and valid method for analysing self-report data. To assess the relationship between time of day of intake and overall and macronutrient intake, multiple linear regression analyses[26] were performed to predict the overall daily intakes on the basis of energy density and the proportions of intake ingested during each period. Since the amount ingested during a period is highly correlated with the total amount eaten over the day the proportion of the day's intake that was eaten during each period was used instead of the absolute amounts. These proportions, along with dietary energy density, were then used in the multiple regressions predicting the absolute amounts ingested over the entire day for each subject individually:

$$Y = a + b_{\mathrm{d}} \times X_{\mathrm{d}} + b_{\mathrm{c}} \times X_{\mathrm{c}} + b_{\mathrm{f}} \times X_{\mathrm{f}} + b_{\mathrm{p}} \times X_{\mathrm{p}},$$

where Y, the total daily intake, is expressed in terms of a constant (a) and the slopes (b_{x}) multiplied by the X_{x} variables for dietary energy density ($b_{\mathrm{d}} \times X_{\mathrm{d}}$), carbohydrate ($b_{\mathrm{c}} \times X_{\mathrm{c}}$), fat ($b_{\mathrm{f}} \times X_{\mathrm{f}}$) and protein ($b_{\mathrm{p}} \times X_{\mathrm{p}}$).

Separate regressions were performed predicting total daily food energy intake, and the overall daily intakes of carbohydrate, fat and protein. Mean standardised regression coefficients (β coefficients) were then calculated over all participants and for male and female participants separately and compared with zero with a t test[26].

To make the results of the multiple regression analyses more concrete, days were identified when the proportions of the daily intake of the individual macronutrients eaten were above or below the mean level for each individual for the morning, afternoon or evening periods. The total amounts eaten on those days of food energy, carbohydrate, fat and protein were then compared. For example, the total amounts ingested on days in which an individual ate a proportion of their total daily carbohydrate intakes during the morning that was greater than the mean level for that individual for the morning were compared with the total amounts ingested on days when the proportion of total carbohydrate in the morning was below the mean level. Then the analysis was completed for days when the proportion of total intake was above and below the mean for the afternoon and a final analysis compared evenings with above and below the mean proportionate intakes. These analyses were repeated for fat intakes and also for protein intakes. Repeated-measures ANOVA were used to compare the intakes for below and above the mean days for the three periods.

Since 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 less than 110 % of their estimated BMR. This criterion is commonly used as a reasonable cut-off for distinguishing underreporting[27,28].

Results

The overall and meal intakes for this dataset have been described in detail in a prior publication[5]. Separate analyses were performed for males and females, for participants of age 18–30, 30–45 and 45–70 years, for normal, overweight and obese participants, and for participants whose reported intakes were greater than 110 % of their estimated RMR. None of these analyses produced results that varied significantly from those obtained for all participants combined. As a result, only the results for all participants are reported. In addition, there were no significant differences obtained for analyses using dietary energy density calculated with or without the inclusion of drinks in the calculation. So, only the results for overall dietary energy density including drinks are reported. All reported results were significant at $\alpha = 0.05$.

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Time of day of macronutrient intake relationships with total daily food energy intake

The total amount eaten over the entire day was associated with the characteristics of the food eaten during different times of the day. The β coefficients from the multiple regressions indicate the strength of the relationships between total daily energy intake and the characteristics of the food eaten during different times of the day. These β coefficients (Fig. 1) predict the total food energy intake over the entire day on the basis of the dietary energy density and the proportions of the individual macronutrients' daily intake for carbohydrate, fat and protein during the morning, afternoon and evening periods. The β coefficients for dietary energy density indicate that the higher the energy density of the food regardless of the time of day, the higher the daily energy intake ($t = 8{\cdot}99$, 9·85, 8·44, for morning, afternoon and evening respectively; Fig. 1), while higher proportions of daily carbohydrate ($t = 4{\cdot}53$) and fat ($t = 29{\cdot}8$), only for the morning period, are associated with lower daily energy intake (Fig. 1). The proportion of intake composed of protein did not have a significant relationship with overall intake during any portion of the day. Hence, the multiple regression analysis indicates that dietary energy density is associated with higher overall intake regardless of time of day, while the higher the proportion of daily carbohydrate and fat eaten in the morning the lower the overall energy intake for the day.

To look, in a little different way, at the relationship of time of day of macronutrient intake with the total daily energy intake, the individuals' intakes on days when they ate relatively less of the macronutrient during a particular period were compared with the days when the same individuals ate relatively more (Fig. 2). Days when the proportions of the daily intake of the individual macronutrients eaten were above or below the mean level for each individual for the morning, afternoon or evening periods and the total amounts eaten on those days were compared. It is shown that when a large portion of daily carbohydrate intake occurs in the morning, overall daily intakes are lower ($t(865) = 3{\cdot}26$; Fig. 2), while when either a large proportion of carbohydrate ($t(865) = 2{\cdot}17$; Fig. 2) or fat intake ($t(865) = 2{\cdot}19$; Fig. 2) occurs in the evening, overall daily intakes are higher.

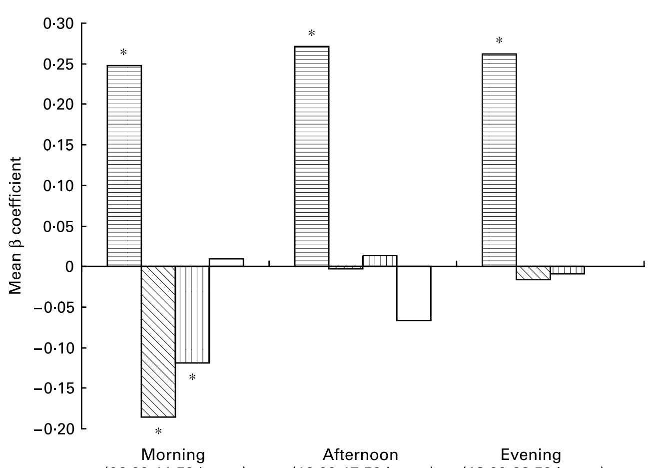

Fig. 1. Predictions of daily energy intake based upon the characteristics of intake eaten during the morning (06.00–11.59 hours), afternoon (12.00–17.59 hours) and evening (18.00–23.59 hours). Mean standardised (β) coefficients from the multiple regressions predicting the total food energy intake over the entire day are presented using four predictors: dietary energy density (▤) and the proportions of the individual macronutrients' daily intake for carbohydrate (▧), fat (▥) and protein (□). Multiple regressions and ANOVA were performed separately for intake occurring during the morning, afternoon and evening periods. *Mean β coefficient is significantly different from 0 ($P<0{\cdot}05$; t test).

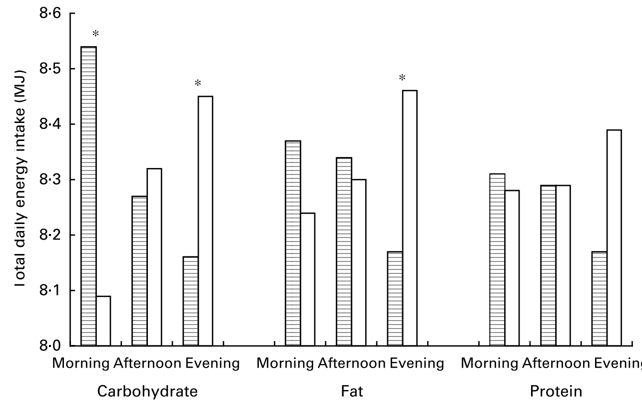

Fig. 2. Mean total daily food energy intake on days when the proportions of the daily intake of carbohydrate, fat and protein eaten were above (□) or below (▤) the mean level for each individual for the morning, afternoon or evening periods. *Below and above the mean days were significantly different ($P<0{\cdot}05$; t test).

Morning, afternoon and evening macronutrient intake relationships with total daily macronutrient intake

The total amount eaten over the entire day of carbohydrate, fat and protein was associated with the characteristics of the food eaten during different times of the day. Dietary energy density had a significant positive relationship with intake regardless of the time of day or the macronutrient predicted. The proportionate intake of the macronutrients, on the other hand, only had significant effects for the morning period. To simplify presentation, only the results from the multiple regressions predicting the total intake of each macronutrient over the entire day on the basis of the characteristics of intake in the morning are presented in Fig. 3.

The β coefficients from the multiple regressions indicate the strength of the relationships between the total daily intake of a macronutrient and the characteristics of the food eaten during the morning. These β coefficients (Fig. 3) predict the total intake of a macronutrient over the entire day on the basis of the morning's dietary energy density and the morning's carbohydrate, fat and protein proportion of the daily macronutrient intake. The β coefficients indicate that the higher the energy density of the food eaten in the morning the higher the daily intake of all three macronutrients, carbohydrate ($t = 8{\cdot}93$), fat ($t = 6{\cdot}41$) and protein ($t = 4{\cdot}27$) (Fig. 3), while the higher the proportion of the total daily intake of carbohydrate eaten in the morning the lower the total intake of carbohydrate over the entire day ($t = 7{\cdot}84$; Fig. 3), the higher the proportion of the total daily intake of fat eaten in the morning the lower the total intake of fat over the entire day ($t = 4{\cdot}07$; Fig. 3) and the higher the proportion of the total daily intake of protein eaten in the morning the lower the total intake of protein over the entire day ($t = 7{\cdot}89$; Fig. 3).

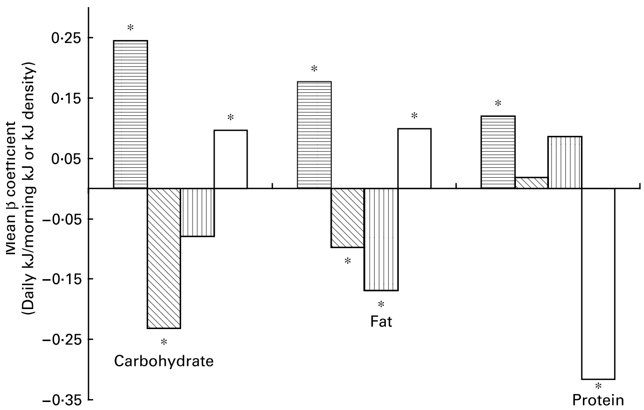

Fig. 3. Predictions of the total daily intake of carbohydrate, fat and protein based upon the characteristics of intake eaten during the morning (06.00–11.59 hours). Mean standardised (β) coefficients from the multiple regressions predicting the total intake of a macronutrient over the entire day are presented using four predictors: dietary energy density (▤) and the proportions of the individual macronutrients' daily intake eaten in the morning for carbohydrate (▧), fat (▥) and protein (□). Multiple regressions and ANOVA were performed separately for intakes of carbohydrates, fats and proteins. * Mean β coefficient is significantly different from 0 ($P<0·05$; t test).

Hence, the multiple regression analysis indicates that the higher the dietary energy density of morning intake the higher the overall daily intake of carbohydrate, fat and protein. On the other hand, the analysis reveals that the greater the proportion of the day's carbohydrate intake that is eaten in the morning the less total carbohydrate will be eaten over the entire day, the greater the proportion of the day's fat intake that is eaten in the morning the less total fat will be eaten over the entire day, and the greater the proportion of the day's protein intake that is eaten in the morning the less total protein will be eaten over the entire day. Hence, there appears to be macronutrient specificity such that the proportion of the daily intake of each macronutrient that is eaten in the morning tends to be maximally inversely associated with overall daily intake of that same macronutrient.

To look, in a slightly different way, at the relationship of time of day of macronutrient intake with the total daily intake of each macronutrient, the individuals' intakes on days when the participants ate relatively more of the macronutrient during a particular period were compared with the days when the same individuals ate relatively less (Figs. 4–6). Days were identified when the proportions of the daily intakes of the individual macronutrients were above or below the mean level for each individual for the morning, afternoon or evening. The total amounts of each individual macronutrient eaten on those days were then compared.

It is shown that for daily carbohydrate intake, only a relatively high intake of carbohydrate in the morning is associated with lower total carbohydrate intake over the day ($t(865)=1·99$; Fig. 4). For daily fat intake, a relatively high intake of carbohydrate ($t(865)=3·00$; Fig. 5) or fat ($t(865)=1·97$; Fig. 5) in the morning is associated with lower total fat intake over the day and only a relatively high intake of fat in the evening is associated with higher total fat intake over the day ($t(865)=2·48$; Fig. 5). Also, for daily protein intake, a relatively high intake of carbohydrate ($t(865)=2·06$; Fig. 6) or protein ($t(865)=4·67$; Fig. 6) in the morning is associated with lower total protein intake

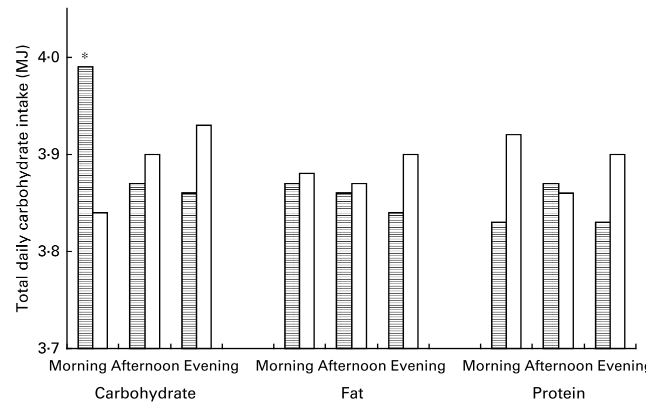

Fig. 4. Mean total daily carbohydrate intake on days when the proportions of the daily intake of carbohydrate, fat and protein eaten were above (□) or below (▤) the mean level for each individual for the morning, afternoon or evening periods. * Below and above the mean days were significantly different ($P<0·05$; t test).

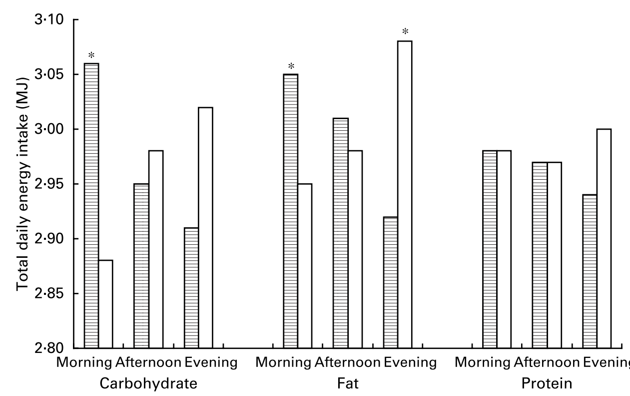

Fig. 5. Mean total daily fat intake on days when the proportions of the daily intake of carbohydrate, fat and protein eaten were above (□) or below (▤) the mean level for each individual for the morning, afternoon or evening periods. * Below and above the mean days were significantly different ($P<0·05$; t test).

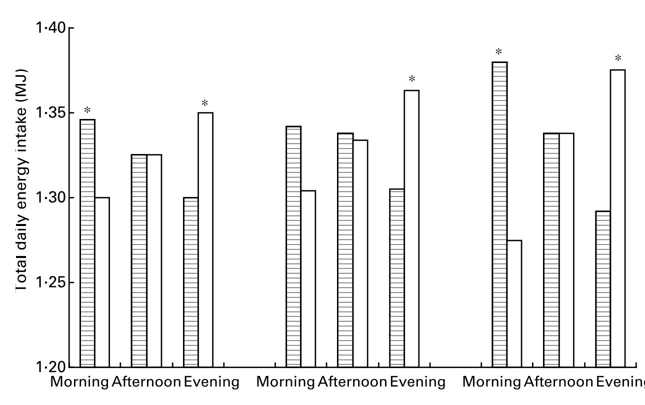

Fig. 6. Mean total daily protein intake on days when the proportions of the daily intake of carbohydrate, fat and protein eaten were above (□) or below (▤) the mean level for each individual for the morning, afternoon or evening periods. * Below and above the mean days were significantly different ($P<0·05$; t test).

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over the day and a relatively high intake of carbohydrate ($t(865) = 2{\cdot}04$; Fig. 6), fat ($t(865) = 2{\cdot}37$; Fig. 6) or protein ($t(865) = 3{\cdot}49$; Fig. 6) in the evening is associated with higher total protein intake over the day.

Discussion

The results reconfirm the prior findings that the intake of a high-energy-density diet during any portion of the day tends to increase 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[5]. The present results extend these findings by demonstrating that the satiating influence of morning intake is primarily due to its carbohydrate content and that the supplementing influence of evening intake is primarily due to its carbohydrate and fat content.

These results, however, further extend these findings and indicate that the morning intake association with reduced total intake is macronutrient specific, with morning carbohydrate, fat and protein intake associated with reduced daily carbohydrate fat and protein intake, respectively. In particular, when the proportion of daily carbohydrate ingested in the morning is high, less total food energy and total carbohydrate is ingested over the entire day. When the proportion of daily fat ingested in the morning is high, less total food energy and total carbohydrate and total fat are ingested over the entire day. Finally, when the proportion of daily protein ingested in the morning is high, less total protein is ingested over the entire day. Evening intake on the other hand appears to supplement overall daily intake. When intake is relatively high in the evening of either total food energy, carbohydrate or fat then overall daily energy intakes tend to be higher. We have previously observed similar macronutrient specificity for the inverse relationship between daily intake and the intake of nutrients 2 and 3 d later[8]. Of course this evidence is strictly correlative in nature, so 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.

Protein intake did not appear to have as large an effect on intake as carbohydrate or fat intake. This, however, may be due to the fact that protein only constituted 16 % of total daily food energy intake reported in the present study. In fact, the larger the proportion of total energy that a particular macronutrient constitutes, the larger the β coefficient observed in the multiple regression predicting total energy intake. The proportion of protein ingested in the morning had a strong negative relationship with the total amount of protein ingested during the day. But, this did not produce a relationship with overall daily intake, as overall energy intake is dominated by carbohydrate and fat intakes. The multiple regressions predict that for each standard deviation change in morning proportional protein there would be only a 1·5 % (124 kJ on average) change in overall intake while for proportional carbohydrate a one standard deviation change predicts a 4·3 % (410 kJ on average) change in overall intake. It is interesting to note that individuals who ate high-protein breakfasts tended to have higher BMI than individuals who ate high-carbohydrate breakfasts[9]. This suggests that the macronutrients may not be equally effective, with protein intake in the morning having a much smaller impact on overall daily intake than carbohydrate or fat.

In the present study a 7 d diet-diary methodology was employed. There is evidence that it is reasonably reliable and valid[29–33] (for a review, see de Castro[24,25]). But it is not absolutely accurate, as it appears to underestimate intake[34–37]. It is important to understand how the inaccuracy might affect the analysis being performed. Underestimation influences the magnitude of the estimates of intake[18]. So, in the present analysis, not only were the absolute values analysed but also the proportions of intake that are magnitude independent. Hence, since 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 (for example, 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. There still are probably unsystematic, random, errors of measurement. But, 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 is, in fact, considerably stronger than indicated by the reported results.

It is interesting to speculate that there may be a connection between the obtained results and the current epidemic of obesity[38,39]. There appears to be a modern trend for children and adolescents to eat very little in the morning and shift the preponderance of their intake till much later in the day[40–42] and for adults to be less likely to eat breakfast[43]. Hence the increase in the incidence of obesity in the population has transpired in parallel with the shift in intake away from the morning toward the night-time. The present results that intake in the morning is associated with decreased overall intake and that intake in the late-night period is associated with higher overall daily intake suggests that the relationship between obesity and the shift in the time of day of intake may not be a spurious relationship. If this is true then encouraging a shift in the daily pattern to one where relatively large amounts of food are eaten in the morning and intake during the evening is restricted might be effective in reducing intake and as a treatment or a preventative measure for obesity. Indeed, it has been shown that overweight and obesity are associated with skipping breakfast[44–48] and eating late in the day[49]. In addition, only 4 % of the individuals who have been successful in losing a substantial amount of weight and keeping it off for a prolonged period of time are breakfast skippers[50].

The magnitude of the associations observed support the potential utility of using the time of day of intake as a variable to manipulate in dietary interventions. For the average reported diet, there is an approximately 1:1 less intake over the day with morning intake. For every 1 kJ more of carbohydrate or fat that was ingested in the morning the present study indicates that there was approximately a 1 kJ less total intake over the entire day. Even looking at the days that participants ate more carbohydrate in the morning than their own

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average morning intake of carbohydrate indicates that approximately 450 kJ less of food energy is ingested over the day. This is significant as it has been speculated that 450 kJ/d in excess intake would be sufficient to account for the obesity epidemic. A reduction of intake by 450 kJ/d, everything else being equal, would burn off the equivalent of 1 kg fat approximately every 73 d or 5 kg fat every year.

The present findings extend these ideas further by suggesting that morning intakes have macronutrient-specific effects and since the preponderance of energy intake is in the form of carbohydrates and fat that morning intake of high-carbohydrate or high-fat foods may be the most effective for reducing overall daily intakes. Indeed, it has been shown that individuals who eat high-carbohydrate breakfasts tend to have lower BMI than individuals who skip breakfast or eat a high-protein breakfast[9]. Greater intakes of ready-to-eat breakfast cereals, which tend to be high in carbohydrates, by children are associated with lower body weights[10,11]. Hence, the literature and the present findings suggest that altering the diurnal patterning of intake may be an effective dietary strategy with a recommendation that a high-carbohydrate breakfast be combined with the intake of low-energy-density foods and a restriction of night-time eating.

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