Metabolic and behavioral consequences of a snack consumed in a satiety state

Corinne Marmonier, Didier Chapelot, and Jeanine Louis-Sylvestre

ABSTRACT
Background: In view of the influence of dietary habits on obesity, human eating patterns merit study.
Objective: We investigated the behavioral and biological consequences of consumption of a 1-MJ snack by subjects in a satiety state.
Design: Eleven lean young men were deprived of time cues and subjected to continuous blood withdrawal over each of 4 sessions scheduled 2 wk apart. The first session was a basal session designed to determine the following in each subject: 1) the amount eaten in an ad libitum lunch; 2) the temporal patterns of plasma concentrations of glucose, insulin, fatty acids, and triacylglycerols between lunch and the spontaneous dinner request; and 3) the latency of the dinner request. In the 3 other sessions, each subject ingested the same lunch as in the basal session and a nutritionally well-balanced snack either 5 min before his individual peak of hyperglycemia observed in the first session, 40 min after this peak, or 120 min before the time he had requested his dinner in the first session.
Results: There was no significant difference in latency of the dinner request or the energy intake at dinner between sessions. Insulin secretion increased but glucose profiles did not change significantly regardless of the time of snack intake.
Conclusion: A snack consumed in a satiety state fails to prolong the intermeal interval and would thus tend to favor storage.


KEY WORDS Snack, appetite control, satiety, postprandial metabolic responses, hormonal responses, behavioral responses, insulin, glucose, fatty acids, men

INTRODUCTION
Because of the importance of dietary habits in the etiology of obesity, the influence of eating patterns on human physiology merits investigation. Animals and humans eat not only to sustain their energy and macronutrient requirements, but also under the influence of a variety of factors, eg, social setting, stress, boredom, and the pleasure of eating a palatable food. In 1955, Mayer (1) postulated that “short-term articulation between energy needs and energy intake was under glucostatic control.” Combined behavioral and metabolic data have shown that there is a link between changes in blood glucose concentrations and spontaneous meal onset. Thus, in rats, the initiation of a meal has been shown repeatedly to be preceded by a decline in blood glucose concentrations (2–7). This was also observed in human subjects deprived of time cues (8). This temporal sequence is consistent with a causal link between the 2 phenomena. Furthermore, whereas some eating episodes are triggered by the presentation of novel foods with strong sensory qualities without a preceding change in blood glucose concentrations (6), a spontaneous decrease in blood glucose concentrations is consistently followed by the search for and consumption of food (7). The transient drop in blood glucose is thought to be the signal of a shortage in immediately available glucose, which is detected by central glucoreceptive elements triggering feeding behavior.

There is now evidence that in free-feeding animals (9) and in free-living humans (10) the intermeal interval depends on both energy intake at the preceding meal and the rate of nutrient utilization. Thus, according to glucostatic theory, after an eating episode, the interval before glucose availability decreases depends on the rate of utilization of available carbohydrates. At any time in the intermeal interval, the amount of available carbohydrate is a function of the carbohydrate content of the previous meal, of the additional glucose provided by gluconeogenesis, and of the amount of glucose spared by fat oxidation.

It was shown experimentally that when a meal is triggered by hunger sensations, blood glucose and insulin concentrations are low and fatty acid concentrations are rising (11). This biological profile is likely to be different when an eating episode is triggered under conditions of satiety. The utilization of the energy substrates might be accordingly altered, inducing a change in glucose disposal. There is now evidence that the habitual consumption of foods between meals contributes to obesity and makes it difficult to lose weight (12–14).

In the present study, we investigated the metabolic and behavioral consequences of a 1-MJ snack ingested at various times during the intermeal interval. The snack mimicked an eating episode triggered neither by hunger sensations nor emotional factors, but...
by a social or environmental occasion (15). To simulate spontaneous prandial pattern conditions, subjects were deprived of time cues from lunchtime until the spontaneous dinner request.

SUBJECTS AND METHODS

Subjects

After approval of the procedure by the ethical committee of the medical school, subjects were recruited through advertisements posted at Xavier Bichat University School of Medicine in Paris. Smokers, trained athletes, persons who admitted to occasionally skipping a meal, persons who habitually ate > 3 meals/d, persons who ate at unusual times, persons who had food allergies, and persons who took medication were excluded. Subjects were also excluded if they reported a personal or family history of diabetes or other metabolic disease or if their body weight had changed in the 3 y before the study. Potential subjects completed a 7-d food diary and those who reported consuming > 35% of energy as fat were excluded from further study. All subjects had low (< 10; maximum score: 21) dietary restraint scores on the Three Factor Eating Questionnaire (16) and had no aversion to the different foods provided throughout the experiment.

Subjects gave their written, informed consent before the start of the experiment and were financially compensated for completing the study. Twelve subjects were recruited but 1 was excluded in the early stages because of poor compliance. Thus, the experiment was completed by 11 lean men aged 20–26 y. Subjects had a mean body mass index (in kg/m²) of 22.0 ± 0.5 (range: 20–25).

Design

A within-subjects design was used in which each subject served as his own control. Subjects were deprived of time cues over each of 4 sessions scheduled 2 wk apart. The first (basal) session was designed to determine the following in each subject: 1) the amount eaten in the ad libitum lunch, 2) the temporal pattern of change in the plasma concentrations of glucose and other metabolic and hormonal indexes from lunch until the spontaneous dinner request, and 3) the latency of the dinner request. In the 3 subsequent sessions (A, B, and C), the metabolic and behavioral consequences of the consumption of a snack were assessed. Subjects underwent these 3 sessions in a counterbalanced order. In session A, the snack was provided to each subject 5 min before the subject’s postprandial hyperglycemia peak in the basal session, ie, when glucose and insulin concentrations were still increasing. In session B, the snack was provided 40 min after this peak, ie, when glucose and insulin concentrations were rapidly decreasing. In session C, the snack was provided to each subject 2 h before the time he had requested his dinner in the basal session, ie, when glucose and insulin concentrations had decreased but were still above their prelunch concentrations. A diagram of the protocol, tracing a hypothetical temporal profile for plasma glucose concentration between lunch and dinner, shows when the snacks were given (Figure 1).

Foods

The lunch was a 2-course meal and consisted of spaghetti Bolognese and a praline-flavored dessert cream (Appendix A). The snack consisted of soft white cheese with strawberry jam and 2 small toasted bread slices. The nutritional composition of the snack is shown in Table 1. The ad libitum dinner was a buffet-style meal in which subjects were presented with a variety of foods and water (Appendix A).

Ratings

Subjects were asked to assess their hunger sensations by repeated ratings on 100-mm visual analogue scales anchored at either end with the French words for none and extreme.
Blood sampling and plasma assays

With use of a specially designed double-lumen catheter (MTB, Amstetten, Germany) inserted into the antecubital vein, heparin-treated blood was withdrawn continuously throughout the session at a flow rate of 0.3 mL/min via a peristaltic pump without any infusion of heparin into the vein (17). Blood samples were collected in tubes every 5 min. The blood took 10 min to flow from the arm to the collection tube. Blood samples were centrifuged immediately at 2000 \( \times \) g for 15 min at 4°C, and plasma was pipetted into 5 different tubes and frozen at \(-26^\circ\text{C}\) until assayed further.

Standard procedures were used to measure concentrations of glucose, insulin, fatty acids, and triacylglycerols. Glucose concentrations were measured by the glucose-oxidase method (1% accuracy, Yellow Springs Instruments glucose analyzer model 23A; Bioblock, Strasbourg, France), insulin concentrations were measured by a single radioimmunologic assay (7% accuracy, Insulin-CT kit; Cis Bio International, Saclay, France), and fatty acid and triacylglycerol concentrations were measured by a colorimetric enzymatic method (both 5% accuracy, C Wako kit and Yellow Springs Instruments glucose analyzer model 23A; Bioblock, Strasbourg, France).

Calculations and statistics

Mean temporal patterns of change in hunger ratings were calculated as follows. Temporal patterns of change between lunch and dinner can be described by postlunch and predinner profiles. For each experimental condition, the postlunch profile was determined by calculating the mean of the subjects’ ratings for each time (every 30 min before and after lunch) up to the time of the earliest dinner request (310 min, as discussed below) of the 4 sessions. For each session, the predinner profile was determined by establishing another time 0, which was the mean time of the dinner request. The mean time of the last hunger rating performed before the dinner request was then calculated, as were the subjects’ hunger ratings at that time. The means of the ratings done by the 11 subjects from 30 to 120 min before the dinner request were calculated.

Moreover, because snack time was dependent on the experimental manipulation, for each snack session we calculated the mean of the hunger ratings obtained just before snack intake and the mean of each of the subsequent 2 ratings. Means were compared with the means obtained at the same times in the basal session.

Postlunch and predinner profiles for the temporal patterns of plasma glucose, insulin, fatty acid, and triacylglycerol concentrations were obtained in the same way as for the hunger rating profiles. Baseline values for plasma glucose, insulin, fatty acid, and triacylglycerol concentrations were calculated by using the first 5 determinations.

Areas under the curve (AUCs) for glucose, insulin, fatty acids, and triacylglycerols were determined as areas over mean baseline. They were calculated over the postlunch and the predinner periods by using the trapezoidal method.

Latency of the dinner request and food intake data were analyzed by repeated-measures analysis of variance (ANOVA) with session type as a within-subject factor. We used SPSS software for

| TABLE 1 | Nutritional composition of the snack |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                  | Quantity | Protein | Fat  | Carbohydrate | Energy |
| High-fat soft white cheese | 75 | 6.0 | 6.0 | 2.3 | 364.1 |
| Low-fat soft white cheese | 25 | 2.1 | 0.9 | 0.9 | 82.7 |
| Strawberry jam    | 15 | 0.1 | 0.0 | 10.4 | 174.5 |
| Small toasted bread | 25 | 2.4 | 2.0 | 18.5 | 425.1 |
| Total snack       | 140 | 10.6 | 8.9 | 32.0 | 1046.4 |

1Danone, Levallois-Perret, France.
2Andros, Biars, France.
3Heudebert, Athis-Mons, France.
RESULTS

At the ad libitum lunch in the basal session, subjects ate 3273 ± 187 kJ and were then served exactly the same amounts of the same foods in the other sessions. On the basis of the individual time course of glycemia in the basal session, the snack was given 43 ± 2 min (range: 35–50 min) after the start of the lunch in session A, 86 ± 4 min (range: 70–105 min) after the start of lunch in session B, and 277 ± 15 min (range: 205–340 min) after the start of lunch in session C.

Hunger ratings

Mean hunger ratings obtained in the 4 different sessions were compared. Analyses showed a main effect of time for postlunch (P < 0.001) and predinner (P < 0.001) ratings, but no significant effect of session type and no time-by-session interaction (Figure 2).

Hunger ratings assessed before lunch were not significantly different between sessions (82.2 ± 5.78 ± 6.78.4 ± 5.3, and 78.5 ± 7 mm for the basal session and sessions A, B, and C, respectively). At the time of the dinner request, mean ratings also did not differ significantly (82.5 ± 3.6, 85.8 ± 4.8, 85.0 ± 4.0, and 80.0 ± 6.0 mm, respectively) and were not significantly different from the prelunch ratings.

Compared with that during the basal session, snack intake in sessions A and B did not significantly change the hunger sensation profile as evidenced by the comparison of the mean of the hunger ratings just before the snack intake with the mean of the 2 subsequent ratings. By contrast, in session C, the mean of the ratings obtained just after the snack intake was significantly lower than the mean of the ratings obtained at the same time in the basal session (36.2 ± 6.0 compared with 49.8 ± 6.2; P < 0.03). Thus, hunger ratings were transiently decreased by the intake of the snack in session C only. In sessions A and B, the snack was presented to the subjects within 105 min of the beginning of lunch, at a time when hunger sensations were low. In session C, we observed that the 25% decrease in hunger sensations that occurred within 30 min of the snack intake was concomitant with an elevation in insulin concentration. However, 1 h after the snack there were no further reductions in hunger sensations.

Latency of dinner request

No significant differences were observed in the latencies of the dinner request between sessions. These latencies were 403 ± 16, 388 ± 12, 414 ± 11, and 387 ± 15 min in the basal session and sessions A, B, and C, respectively.

Energy intakes

Because energy intake from the ad libitum dinner did not differ significantly between sessions (Figure 3), total energy intake was significantly higher in sessions A, B, and C (in which the snack was consumed) than in the basal session.

Temporal metabolic and hormonal changes from lunch to the time of the dinner request

As expected, ANOVA of each set of postlunch and predinner profiles showed a main effect of time (P < 0.001 and P < 0.001, respectively). Baseline values for plasma concentrations of glucose, insulin, fatty acids, and triacylglycerols were not significantly different between sessions (Table 2).

Plasma glucose

Postlunch and predinner profiles of plasma glucose concentrations in the basal session and in sessions A, B, and C are shown in Figure 4 (A–C). Analysis of these profiles showed no significant effect of session type and no time-by-session interaction. The AUCs were also not significantly different between sessions (Figure 5).

At the time of dinner request, mean glucose concentrations were 4.69 ± 0.12, 4.66 ± 0.09, 4.54 ± 0.13, and 5.15 ± 0.18 mmol/L in the basal session and in sessions A, B, and C, respectively (NS). These concentrations were not significantly different from the mean glucose concentrations at the beginning of lunch (4.76 ± 0.13, 4.73 ± 0.10, 4.58 ± 0.11, and 4.65 ± 0.08 mmol/L, respectively).

Plasma insulin

Plasma insulin profiles are illustrated in Figure 6 (A–C). Mean profiles during the basal session were as expected for a postprandial condition. Profiles obtained in other sessions showed an increase in insulin secretion corresponding to snack intake.

ANOVA of the postlunch and predinner profiles showed an effect of session type (P = 0.006 and P = 0.005, respectively) and a time-by-session interaction (P < 0.001 and P < 0.001, respectively). Post hoc comparisons showed that in sessions A (P = 0.018) and B (P = 0.007) but not in session C, the postlunch profiles were significantly different from the postlunch profile obtained in the basal session. In session C (P = 0.002) but not in sessions A and B, the predinner profile was significantly different from the predinner profile obtained in the basal session.

The contrast analysis conducted at each time point showed that in session A, plasma insulin concentrations were significantly higher than in the basal session from 95 to 220 min after the beginning of the lunch (P = 0.05–0.001). In session B, plasma insulin concentrations were higher than in the basal session from 75 min after the beginning of lunch to the end of the postlunch profile and also over 15 min at the beginning of the predinner profile (P = 0.05–0.001). In session C, insulin concentrations were higher than in the basal session from 100 min before the dinner request to the end of the experiment.

Mean insulin AUCs were significantly different between sessions because more insulin was secreted during the intemal interval when a snack was ingested (Figure 5). Thus, insulin AUCs in sessions A and B were significantly different from the basal session AUC for the postlunch profile (P < 0.05 and P < 0.002, respectively). In session C, the insulin AUC was significantly different from the basal session AUC for the predinner profile (P < 0.03). The effects on the insulin AUC of eating a snack during the ascending or descending phase of postprandial hyperglycemia were not significantly different. Session C
FIGURE 2. Mean (±SEM) postlunch (solid lines) and predinner (dashed lines) temporal profiles for hunger ratings in the basal session (open symbols) compared with session A (filled symbols; A), the basal session (open symbols) compared with session B (filled symbols; B), and the basal session (open symbols) compared with session C (filled symbols; C). The thin arrow at 0 min on the x axis indicates lunchtime; the open arrows above the curve indicate the snack intake time in session A (ie, 5 min before the peak of postprandial hyperglycemia as determined in the basal session), session B (ie, 40 min after the peak), and session C (ie, 120 min before the time of the dinner request in the basal session); and the thick arrows above and below the curves indicate the time of the dinner request. n = 11. There were no significant differences between sessions.
could not be readily compared with the others because the insulin concentration was still high at the end of the test.

Plasma insulin concentrations at the time of the dinner request were 75.5–14.5, 101.0–14.5, 80.0–19.1, and 217.1–60.5 pmol/L in the basal session and in sessions A, B, and C, respectively. Insulin concentrations in session C were significantly higher than those in the basal session ($P = 0.03$), in session A ($P = 0.05$), and in session B ($P = 0.04$).

**Plasma fatty acids**

Postlunch fatty acid profiles were not significantly different between sessions: fatty acid concentrations rose during the first 20 min and decreased thereafter. The predinner profiles, however, differed significantly between sessions ($P = 0.04$) and there was a significant time-by-session interaction ($P = 0.001$). As shown in Figure 7 (A–C), the predinner profile obtained in session A was not significantly different from the same profile obtained in the basal session ($P = 0.03$), in session A ($P = 0.05$), and in session B ($P = 0.04$).

**Plasma triacylglycerols**

Neither the postlunch nor the predinner profiles of plasma triacylglycerol concentrations or AUCs differed between sessions. Furthermore, at the time of the dinner request, plasma triacylglycerol concentrations were not significantly different between sessions [Figure 8 (A–C) and Figure 5].

**DISCUSSION**

In the present study, subjects were deprived of temporal cues from lunchtime until they requested dinner. Under these conditions,
FIGURE 4. Mean (+SEM) postlunch and predinner temporal profiles for plasma glucose concentrations in the basal session (open symbols) compared with session A (filled symbols; A), the basal session (open symbols) compared with session B (filled symbols; B), and the basal session (open symbols) compared with session C (filled symbols; C). The thin arrow at 0 min on the x axis indicates lunchtime; the open arrows above the curve indicate the snack intake time in session A (ie, 5 min before the peak of postprandial hyperglycemia as determined in the basal session), session B (ie, 40 min after the peak), and session C (ie, 120 min before the time of the dinner request in the basal session); and the thick arrows above and below the curves indicate the time of the dinner request. For clarity, SEMs are indicated every 30 min only. Because blood was drawn continuously and collected every 5 min, the width of the symbols equals 5 min. n = 11. There were no significant differences between sessions.
we showed that the intake of a well-balanced snack providing 1 MJ and consumed at various times over the intermeal interval, ie, under conditions of satiety, had no influence on either the latency of the dinner request or the energy intake at dinner. In other words, the snack intake did not change the satiating effect of the lunch. This result agrees with the findings of Rolls et al (18) and Porrini et al (19). Rolls et al found that neither a high-carbohydrate nor a high-fat snack (both 1.46 MJ) consumed 180 min before a meal reduced subsequent food intake. Porrini et al obtained similar results with a less energetic high-protein or high-fat snack (0.65 and 0.79 MJ, respectively) consumed 120 min before a test meal.

The negative result of the present study might have been because we did not have enough subjects to discern a statistically significant result. In a companion study (C Marmonier et al, unpublished observations, 1999) performed in the same group of subjects, we showed that the intake of a 1-MJ high-fat, high-carbohydrate, or high-protein snack 240 min after lunch (the same lunch as in the present experiment) significantly delayed the dinner request by 25, 35, and 60 min, respectively. It seems, therefore, that under our experimental conditions, this sample size was large enough to identify a 25-min difference in satiety duration.

When subjects are subjected to a fixed intermeal interval, the meal is likely to be presented either before or after the endogenously induced hunger sensation. In the first case, de Castro (20) showed that meal intake is correlated with premeal stomach energy content, which is clearly a function of the length of the fixed interval. In the second case, when the meal is delayed, counterregulatory mechanisms lead to increased hepatic glucose production that compensates for the lack of immediate glucose availability. Therefore, measuring meal intake after a fixed intermeal interval does not accurately assess the satiety effect of the preceding intake. Such a measurement only enables comparisons if the fixed interval is consistently too short or too long. The satiety power of intakes is more accurately evaluated by measuring the onset latency of the next meal when freely requested.

In our subjects, who were isolated from external cues liable to trigger meal onset, we found that none of the snacks altered the intermeal interval. In a previous study using this procedure, we showed that the addition of 1588 kJ fat to a lunch significantly delayed the onset of dinner by \( < 38 \) min but did not change energy intake at dinner. It was calculated that such an increase in the latency of the dinner request may have stemmed from a carbohydrate savings of \( < 10 \) g, corresponding to the oxidation of 4–5 g fat (11). We thus had reason to suppose that a well-balanced...
FIGURE 6. Mean (±SEM) postlunch and predinner temporal profiles for plasma insulin concentrations in the basal session (open symbols) compared with session A (filled symbols; A), the basal session (open symbols) compared with session B (filled symbols; B), and the basal session (open symbols) compared with session C (filled symbols; C). The thin arrow at 0 min on the x axis indicates lunchtime; the open arrows above the curve indicate the snack intake time in session A (ie, 5 min before the peak of postprandial hyperglycemia as determined in the basal session), session B (ie, 40 min after the peak), and session C (ie, 120 min before the time of the dinner request in the basal session); and the thick arrows above and below the curves indicate the time of the dinner request. For clarity, SEMs are indicated every 30 min only. Because blood was drawn continuously and collected every 5 min, the width of the symbols equals 5 min. n = 11. *Significant difference between concentrations at the same times, P < 0.05.
FIGURE 7. Mean (±SEM) postlunch and predinner temporal profiles for plasma fatty acid concentrations in the basal session (open symbols) compared with session A (filled symbols; A), the basal session (open symbols) compared with session B (filled symbols; B), and the basal session (open symbols) compared with session C (filled symbols; C). The thin arrow at 0 min on the x axis indicates lunchtime; the open arrows above the curve indicate the snack intake time in session A (ie, 5 min before the peak of postprandial hyperglycemia as determined in the basal session), session B (ie, 40 min after the peak), and session C (ie, 120 min before the time of the dinner request in the basal session); and the thick arrows above and below the curves indicate the time of the dinner request. For clarity, SEMs are indicated every 30 min only. Because blood was drawn continuously and collected every 5 min, the width of the symbols equals 5 min. n = 11. *Significant difference between concentrations at the same times, P < 0.05.
FIGURE 8. Mean (±SEM) postlunch and predinner temporal profiles for plasma triacylglycerol concentrations in the basal session (open symbols) compared with session A (filled symbols; A), the basal session (open symbols) compared with session B (filled symbols; B), and the basal session (open symbols) compared with session C (filled symbols; C). The thin arrow at 0 min on the x axis indicates lunchtime; the open arrows above the curve indicate the snack intake time in session A (ie, 5 min before the peak of postprandial hyperglycemia as determined in the basal session), session B (ie, 40 min after the peak), and session C (ie, 120 min before the time of the dinner request in the basal session); and the thick arrows above and below the curves indicate the time of the dinner request. For clarity, SEMs are indicated every 30 min only. Because blood was drawn continuously and collected every 5 min, the width of the symbols equals 5 min. n = 11. There were no significant differences between sessions.
1046-kJ snack containing 32 g carbohydrate (Table 1) consumed between meals would lengthen the intermeal interval. The temporal metabolic and hormonal changes that we observed provide some clues as to the absence of this result.

We observed no significant change in glucose profiles but a conspicuous increase in insulin secretion after snack intake. The absence of change in the glucose profiles suggests either a potentiated insulin secretion, an increase in insulin sensitivity, or both. Potentiation of insulin release after priming with glucose has been shown in humans (21). It has also been shown that the increase in insulin response to glucose in thin and nonobese subjects is directly related to the preprandial insulin concentration (22). Because the snacks were provided to our subjects at a time when glucose and insulin concentrations were above basal concentrations, insulin secretion may have been potentiated. At the same time, particularly in sessions A and B, it is also likely that insulin action was enhanced (23). Both of these processes could lead to enhanced glucose disposal, which may explain why snack ingestion failed to prolong the intermeal interval.

Note that when the snack was consumed early in the intermeal interval (session A), we observed an increased in insulin secretion, no significant change in the glucose profile, and also no significant change in the fatty acid profile compared with the basal session. When insulin concentrations are high, glucose oxidation is close to its maximum rate (24, 25). The enhanced glucose disposal might therefore be mainly due to increased glucose storage. Because glucose oxidation was increased not at all or only slightly, fat oxidation, which was already low at that time, was not likely to have been reduced. Thus, consumption of the snack early in the intermeal interval may have led to glucose storage and no fat saving.

When the snack was given later, the lack of effect on the intermeal interval is more likely explained by the effect of the snack-induced insulin secretion on fatty acid oxidation. As noted by Bonadonna et al (25), “adipose tissue is exquisitely sensitive to the inhibitory effect of insulin on FFA [free fatty acid] release.” This was shown in sessions B and C when the snack was consumed either in the descending part of the postprandial hyperglycemia or later: the predinner increase in fatty acid concentrations was actually partially or totally suppressed. This is important because fat oxidation is correlated with and roughly determined by plasma fatty acid concentrations (26, 27). Moreover, as suggested by the Randle glucose–fatty acid cycle (28) and confirmed by experiments in healthy subjects (29), the elderly (30), and subjects with type 2 diabetes (31), a reduction in fatty acid oxidation enhances glucose oxidation and storage. So, when the snack was consumed later in the interval, the snack-induced insulin secretion may have prevented the utilization of fatty acids for energy needs at the expense of an increase in glucose oxidation. This would effectively save fat.

On all 3 test days, subjects consumed the mandatory snack in a satiety state. As the subjects ingested more energy, they secreted more insulin but, as noted above, examination of the ensuing metabolic profiles pointed to a potentiation of insulin secretion. The situation is completely different when meal frequency is increased for the same energy intake. Studies in healthy subjects have shown that increased meal frequency reduces insulin and glucose responses (32, 33). Further studies that focus on the substrate oxidative pattern by measuring gas exchanges will be conducted to confirm our hypotheses. Such measurements should also provide insights into energy expenditure, eg, the possible increase in thermogenesis induced by the snack intake.

It is noteworthy that when the subjects requested their dinner, both hunger ratings and mean glucose concentrations were not significantly different between sessions. Insulin and fatty acid concentrations were quite different in the different sessions, however, suggesting that insulin and fatty acids are not directly involved in the motivation to eat (hunger stimulus). The triacylglycerol profiles were significantly not different across sessions. This lack of difference may be ascribed to the similar composition of the lunch and snack: both were well balanced and their percentage of fat energy was not different.

Given the different metabolic and hormonal consequences of a well-balanced snack consumed at various times during the intermeal interval, it seems that the answer to the question posed by Blair (13) some years ago, “When are calories most fattening?” is that calories seem to be most fattening when they are ingested under conditions of satiety, particularly after the peak of postprandial hyperglycemia. However, because the effects may be a function of the composition of the snack, it would be interesting to determine whether high-carbohydrate, high-fat, and high-protein intakes yield the same effects.

We thank Paul Valensi for helping to make this study possible.

REFERENCES


APPENDIX A
Food items provided at the lunch and free food choice items provided during the ad libitum dinner

<table>
<thead>
<tr>
<th>Food items</th>
<th>Energy</th>
<th>Protein % by wt</th>
<th>Fat % by wt</th>
<th>Carbohydrate % by wt</th>
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</thead>
<tbody>
<tr>
<td>Lunch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spaghetti Bolognese</td>
<td>5.2</td>
<td>5.5</td>
<td>3.6</td>
<td>17.5</td>
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<td>Praline-flavored dessert cream</td>
<td>6.19</td>
<td>4.5</td>
<td>5.0</td>
<td>21.2</td>
</tr>
<tr>
<td>Ad libitum dinner</td>
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<td></td>
<td></td>
<td></td>
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<td>6.3</td>
<td>29.1</td>
<td>3.8</td>
<td>0.0</td>
</tr>
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<td>Ham</td>
<td>4.6</td>
<td>19.5</td>
<td>3.3</td>
<td>0.6</td>
</tr>
<tr>
<td>Eggs (hard boiled)</td>
<td>6.44</td>
<td>12.5</td>
<td>11.1</td>
<td>1.0</td>
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<tr>
<td>Tabouleh</td>
<td>5.23</td>
<td>3.8</td>
<td>2.5</td>
<td>21.8</td>
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<td>Green peas</td>
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<td>4.06</td>
<td>6.0</td>
<td>5.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Chocolate dessert cream</td>
<td>5.37</td>
<td>4.9</td>
<td>4.7</td>
<td>16.6</td>
</tr>
<tr>
<td>Fruit yogurt</td>
<td>4.44</td>
<td>2.3</td>
<td>2.4</td>
<td>18.8</td>
</tr>
<tr>
<td>Butter cookies</td>
<td>19.63</td>
<td>6.0</td>
<td>17.0</td>
<td>73.0</td>
</tr>
<tr>
<td>Chocolate cookies</td>
<td>19.56</td>
<td>6.6</td>
<td>22.9</td>
<td>58.7</td>
</tr>
<tr>
<td>Dark chocolate</td>
<td>23.02</td>
<td>5.0</td>
<td>30.0</td>
<td>65.0</td>
</tr>
</tbody>
</table>

1 Danone, Levallois-Perret, France.
2 Monoprix SMB, Paris.
3 Lu, Athis-Mons, France.