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ORIGINAL CONTRIBUTION

Contribution of energy density and food quantity to short-term fluctuations of energy intake in normal weight and obese subjects

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Abstract
Background In normal weight subjects it is known that day-to-day energy intake (EI) can vary substantially while this question has not been examined in obese subjects. From acute feeding experiments one would assume that these perturbations are mainly due to differences in food energy density (ED). However, food quantity (FQ) during single meals, number of meals, cognitive and sensory mechanisms may also contribute to the modification of EI.
Objective and design To obtain more detailed information about day-to-day variations of food intake food diaries recorded during 10 consecutive days of 280 obese and 100 normal weight subjects were examined.
Results The chronological analysis shows a fairly constant pattern for EI, FQ and ED in both groups. The group analysis, however, masks individual fluctuations since the coefficients of variation were between 20 and 24% for the three parameters, respectively. This corresponds to a range of 1,200 kcal. Sixty-five percent can be accounted for changes in FQ and 35% as the result of variations in ED. Snacks between main meals account for 20% of daily EI but only 10% of FQ. Furthermore, snack EI is not compensated during main meals.
Conclusion Small day-to-day changes of EI are due to increased meal quantities while greater fluctuations are also due to higher food ED. The present data suggest that modification of FQ by cognitive and sensory factors plays an important role in the variation of daily EI under real life conditions with no major difference between normal weight and obese subjects.

Keywords Daily meal intake · Main meals · Snacks · Body mass index

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Introduction

Daily energy intake (EI) is determined by a large number of factors that influence ingestive behavior such as hunger and satiety sensations, taste and smell of food items, cognitive and environmental functions as well as psychological and social aspects [3, 28]. All these have an effect on the quantity and quality of ingested food during single meals and affect the frequency of daily meal intake. Several studies in obese and normal weight subjects have shown that the acute termination of food intake depends on satiety signals that are predominantly activated by the amount of ingested food while its energy content is of minor importance [8, 10, 21, 28]. Thus, food of higher energy density (ED) will inevitably favor greater EI at identical degrees of satiation which has been demonstrated not only in acute but also in prolonged feeding experiments [33, 34]. Moreover, ED and portion size have combined effects on acute EI [15, 23, 24]. Epidemiological studies have presented evidence for a good correlation between food ED and overall EI in large populations [13, 16, 20]. All these findings are of great interest for the development of dietary strategies of obesity treatment and in fact, some recent studies have shown the efficacy of food items with low ED to improve weight loss [6, 17, 22].

For several decades it is known that day-to-day EI can vary substantially [35], which has been demonstrated in normal weight subjects. From the data of the above mentioned acute feeding experiments one would expect that these perturbations are mainly due to differences of food ED assuming that under more real life eating conditions food quantity (FQ) would show a constant pattern similar to the experimental laboratory setting of acute feeding experiments. On the other hand, an important interaction of cognitive and sensory cues with single meal quantity and meal frequency cannot be excluded and is most likely of relevance. The relative contribution of neuroendocrine regulatory systems versus the cognitive interference has been a matter of debate for years [2, 12]. To obtain more detailed information in this context the day-to-day variation of food intake was analyzed in 280 overweight and obese and 100 normal weight subjects during a 10-day period of habitual eating behavior.

Research design and methods

A total of 280 overweight and obese patients and 100 normal weight subjects were evaluated. The patients contacted the outpatient clinic of the department of nutritional medicine for the treatment of their weight problem in the years 2005 and 2006. Nearly all patients had a history of various diets for weight loss and those included in this analysis had maintained their weight for at least 12 months without any period of intentional or spontaneous weight loss. The normal weight subjects were recruited by advertisement and the selection was made according to age and gender to match the obese group as much as possible.

The demographic characteristics are summarized in Table 1. As part of our routine treatment program all patients have to complete a food diary over ten consecutive days prior to the start of therapy. They are instructed to record in as detailed a manner as possible every item that they either eat or drink, the time they consumed it, the amount they ate and how the food was prepared. To improve the motivation to accurately report their habitual food intake patients were told that an accurate recording of their usual intake improves individually adapted changes of their personal eating habits during subsequent therapy. They were told that the most preferred food items of their usual diet will remain unchanged as much and as long as possible to prevent underreporting especially of snacks with high ED.

They were informed that record keeping can produce a change in nutrient intake and they should not try to alter their normal food intake since this could be disadvantageous for the subsequent recommendations during dietary counseling. They should try to record at the time of meal ingestion as much and as often as possible to minimize problems of correctly remembering details and especially the quantity of ingested food items. They should use a scale as often as possible. They were told that the quantity of recorded food items is extremely important for the ensuing therapy. All patients were handed out a booklet with examples of characteristic portion sizes in case of eating out. The same information was given to the normal weight subjects.

Table 1 Demographic characteristics of study population (mean ± SD)

	Obese	Normal weight
n	280	100
Sex (female/male)	205/75	67/33
Age (year)	45 ± 11.5	42 ± 8.7
Body weight (kg)	108 ± 25.9	67 ± 7.3
BMI (kg/m^2)	36.6 ± 8.8	22.5 ± 1.9

Data analysis

Dietary protocols were calculated with the program PRODI 4.5 Expert (Kluthe, Freiburg, Germany). Main meals were divided into breakfast, lunch and dinner. Patients were told to identify main meals as breakfast, lunch and dinner specifically in their records and to indicate the respective time periods. All food items ingested between breakfast and lunch were considered as morning snack. The afternoon snack comprised the time period between lunch and dinner and the evening snack considered all food items

Table 2 Food intake data based on the 10-day recording period of obese ($n = 2{,}800$ dietary protocols) and normal weight subjects ($n = 1{,}000$ dietary protocols) (mean ± SD) and coefficient of variation

	Obese	Normal weight
Food quantity (g/day)	1,087 ± 390	1,071 ± 370
Total energy intake (kcal/day)	2,024 ± 705	2,055 ± 667
Solid food energy intake (kcal/day)	1,668 ± 642	1,778 ± 598*
Liquid energy intake (kcal/day)	356 ± 287	277 ± 282
Energy density (kcal/g)	1.59 ± 0.47	1.72 ± 0.46*
Coefficient of variation (%)		
Quantity	24.3 ± 8.6	23.7 ± 9.0
Energy	23.8 ± 8.8	23.6 ± 9.0
Energy density	22.1 ± 7.4	20.6 ± 6.6

*$P < 0.05$ or less between groups

following dinner. Energy containing beverages were recorded separately and are not included in the calculations. The ED of each food item was based on the consumed quantity and its energy content and expressed as kilocalorie per gram ingestible food. A detailed analysis of the consumed food items of the obese group has recently been reported [29, 30].

For the calculation of the coefficient of variation (CV) of each individual's food intake, the mean ± SD was calculated for the 10 days and SD divided by the mean value times 100 gave the CV. To assess the individual day-to-day fluctuations of food intake with greater transparency for the entire group data were ranked according to daily EI. The new day r1 represents each individual's day of lowest EI and correspondingly day r10 is the one with the highest EI. All other days are ranked in between.

For statistical analysis *t* test for paired or unpaired data was employed, where appropriate correction for multiple testing was made according to Bonferroni–Holm. *P* values of 0.05 or less were considered significant. All data were analyzed by using SPSS (version 11.5).

Results

Average food intake during the entire recording period is shown in Table 2. FQ was not different and so was total EI. Solid food EI and ED, however, was significantly lower in obese subjects (Table 2).

The chronological intake data are shown in Fig. 1 In both groups there is little day-to-day difference of mean values of all three parameters. Such a group analysis, however, masks the perturbations observed in individual patients which is illustrated in Fig. 1. These day-to-day fluctuations exist in all subjects which is reflected by the substantial coefficients of variation between 20 and 24% for the three parameters evaluated (Table 2).

Ranked food intake

For a greater transparency of the range of fluctuations data were ranked on the basis of each subject's daily EI. The corresponding data are shown in Table 3. Mean EI varies over a wide range of 1,200–1,300 kcal/day

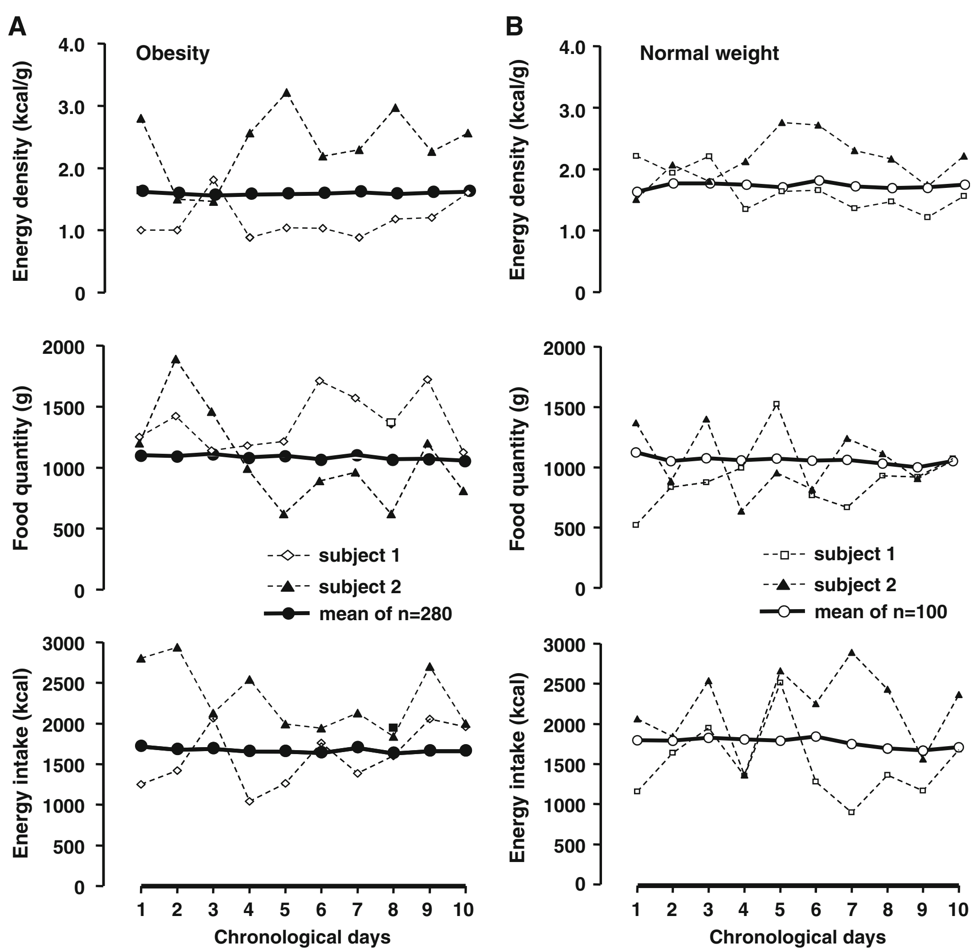

Fig. 1 Mean daily energy intake, food quantity and energy density over ten consecutive days in 280 obese subjects and in 2 single obese subjects (**a**) and mean of 100 normal weight subjects and 2 single normal weight subjects (**b**)

Table 3 Daily energy intake, food quantity and energy density of 280 obese subjects and of 100 normal weight subjects on the basis of a ranking of each individual's minimum to maximum daily energy intake (mean ± SEM)

Ranked days	Obese subjects			Normal weight subjects		
	Energy (kcal)	Quantity (g)	Energy density (kcal/g)	Energy (kcal)	Quantity (g)	Energy density (kcal/g)
r1						
All meals	1,089 ± 23.4	838 ± 20.2	1.40 ± 0.03	1,166 ± 42.0	803 ± 31.3	1.54 ± 0.05
Without snacks	968 ± 20.4^{b}	755 ± 17.9^{b}	1.39 ± 0.03	945 ± 35.0^{b}	655 ± 26.9^{b}	1.55 ± 0.06
r2						
All meals	1,263 ± 23.7^{*,a}	924 ± 19.5^{*,a}	1.45 ± 0.03	1,371 ± 40.3^{*,a}	944 ± 34.0^{*,a}	1.53 ± 0.04
Without snacks	1,105 ± 19.7^{*,a,b}	814 ± 17.2^{*,a,b}	1.44 ± 0.03	1,099 ± 38.7^{*,a,b}	777 ± 31.5^{*,a,b}	1.51 ± 0.04
r3						
All meals	1,391 ± 26.0^{*,a}	982 ± 19.4^{*,a}	1.49 ± 0.03^{a}	1,506 ± 43.1^{*,a}	938 ± 31.7^{a}	1.69 ± 0.05^{*,a}
Without snacks	1,206 ± 22.1^{*,a,b}	866 ± 17.1^{*,a,b}	1.47 ± 0.03^{a}	1,170 ± 39.4^{a,b}	739 ± 26.8^{a,b}	1.66 ± 0.04*
r4						
All meals	1,497 ± 27.7^{*,a}	1,031 ± 21.0^{*,a}	1.52 ± 0.03^{a}	1,613 ± 43.8^{*,a}	1,023 ± 34.6^{*,a}	1.66 ± 0.04
Without snacks	1,287 ± 25.1^{*,a,b}	908 ± 18.1^{*,a,b}	1.49 ± 0.03^{a,b}	1,255 ± 39.1^{*,a,b}	824 ± 29.1^{*,a,b}	1.58 ± 0.04^{b}
r5						
All meals	1,603 ± 29.6^{*,a}	1,055 ± 20.3^{a}	1.60 ± 0.03^{*,a}	1,707 ± 43.9^{*,a}	1,068 ± 30.4^{a}	1.66 ± 0.04
Without snacks	1,366 ± 25.7^{*,a,b}	927 ± 18.1^{a,b}	1.55 ± 0.03^{*,a,b}	1,303 ± 39.0^{a,b}	861 ± 28.5^{a,b}	1.58 ± 0.04^{b}
r6						
All meals	1,700 ± 30.7^{*,a}	1,104 ± 22.6^{*,a}	1.62 ± 0.03^{a}	1,799 ± 44.3^{*,a}	1,091 ± 33.0^{a}	1.72 ± 0.04^{a}
Without snacks	1,462 ± 26.9^{*,a,b}	968 ± 19.2^{*,a,b}	1.59 ± 0.03^{a,b}	1,409 ± 43.1^{*,a,b}	887 ± 29.8^{a,b}	1.65 ± 0.04^{b}
r7						
All meals	1,805 ± 32.0^{*,a}	1,142 ± 21.7^{*,a}	1.65 ± 0.03^{a}	1,909 ± 45.6^{*,a}	1,126 ± 36.3^{a}	1.78 ± 0.04^{a}
Without snacks	1,500 ± 27.0^{*,a,b}	987 ± 18.4^{a,b}	1.59 ± 0.03^{a,b}	1,461 ± 44.5^{a,b}	887 ± 33.1^{a,b}	1.76 ± 0.05^{*,a}
r8						
All meals	1,925 ± 35.2^{*,a}	1,203 ± 21.9^{*,a}	1.65 ± 0.02^{a}	2,040 ± 49.7^{*,a}	1,176 ± 35.8^{a}	1.81 ± 0.05^{a}
Without snacks	1,619 ± 31.7^{*,a,b}	1,047 ± 20.0^{*,a,b}	1.60 ± 0.03^{a,b}	1,596 ± 52.3^{*,a,b}	939 ± 33.0^{a,b}	1.76 ± 0.05^{a,b}
r9						
All meals	2,077 ± 38.9^{*,a}	1,242 ± 24.3^{a}	1.75 ± 0.03^{*,a}	2,187 ± 50.2^{*,a}	1,205 ± 32.6^{a}	1.89 ± 0.05^{a}
Without snacks	1,711 ± 32.1^{*,a,b}	1,059 ± 20.6^{a,b}	1.69 ± 0.03^{*,a,b}	1,652 ± 52.0^{a,b}	962 ± 31.7^{a,b}	1.78 ± 0.05^{a,b}
r10						
All meals	2,325 ± 44.5^{*,a}	1,346 ± 25.3^{*,a}	1.79 ± 0.03^{a}	2,482 ± 62.7^{*,a}	1,336 ± 40.7^{*,a}	1.94 ± 0.05^{a}
Without snacks	1,902 ± 36.4^{*,a,b}	1,145 ± 22.4^{*,a,b}	1.73 ± 0.03^{a,b}	1,883 ± 61.7^{*,a,b}	1,045 ± 34.4^{*,a,b}	1.87 ± 0.05^{a,b}

Significant difference of $P < 0.05$ or less *vs. the preceding day, ^{a}vs. day r1, ^{b}of all meals vs. without snacks

between the lowest and the highest intake in both groups. This is paralleled by differences of FQ in the range of 500 g/day while ED increased by 0.40 kcal/g, respectively. As expected by definition EI of ranked days was significantly higher compared to the immediately preceding day. For FQ a similar stepwise day-to-day increase was observed in the obese group with the exception of days r5 and r9 which were not significantly different from the respective preceding day. On these 2 days ED was significantly higher while on all other days the small changes of ED did not reach the level of significance on a day-to-day basis. In contrast to the obese group FQ in normal weight subjects was not significantly different from the preceding day except for days r2, r 4 and r10. The same pattern was observed for ED with only one difference on day r3. Compared to day r1 EI and FQ were significantly higher from day r2 onwards in both groups while for ED significant differences began on day r3 in the obese and on day r6 in the normal weight group (Table 3). Figure 2 shows the percent change in relation to day r1 in both groups. Approximately two-thirds of acute increases of EI can be explained by a greater daily FQ while one-third can be ascribed to a greater ED of consumed food items.

Role of snacks

Snacks contribute significantly by 10–25% to FQ and EI in normal weight and obese subjects (Table 3). In the obese group the contribution of snacks to daily meal size and EI was less than in the normal weight subjects (Fig. 3) and this was largely independent of the magnitude of daily EI. The relative contribution of snacks became slightly greater with increasing daily EI. The number of snacks is directly related to daily food and EI in both groups which is shown in Fig. 4 indicating that snack consumption is not compensated by reduced food intake during main meals. Nevertheless, these data demonstrate that snacks only account for a small part of the day-to-day variations of food intake while the major changes are due to differences of the main meals.

Discussion

The present study demonstrates for the first time a substantial day-to-day variation of food and EI in obese subjects and it confirms previously published data of day-to-day variations of EI in normal weight subjects [35]. Moreover, it demonstrates that consumption of FQ also varies considerably in the normal weight group. In both groups total daily EI is in the same range of the age and gender related groups of the recent National Survey of Food Intake II in Germany [19]. Principally, under- or over-reporting of food intake can not be excluded. Whenever it occurs it may differ systematically between subjects such that certain participants tend to under- or overestimate more than others [4]. However, the results of the present study are based on changes of intake that are calculated individually for each subject. Furthermore, in large populations this problem is of minor relevance [18].

The magnitude of day-to-day variations of food intake becomes more transparent with an intraindividual ranking. Within the examined time period of 10 days, EI changed by 1,200–1,300 kcal in both groups. Differences of daily EI can be due to (1) different quantities of food during single meals, (2) differences of ED of ingested food items

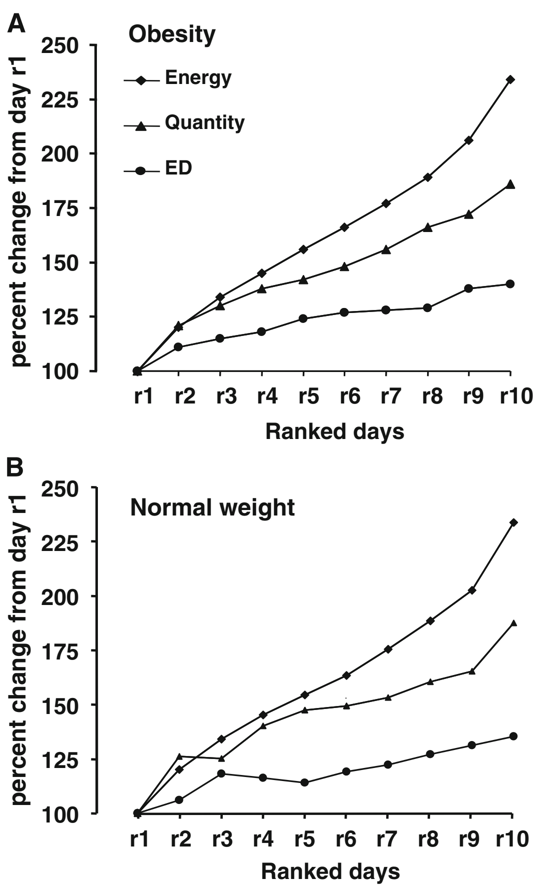

Fig. 2 Relative increase of energy intake, food quantity and energy density (ED) in comparison to the day of each subject's lowest energy intake (*r1*). *Panel* **a** obese subjects ($n = 280$), *panel* **b** normal weight subjects ($n = 100$) (mean values)

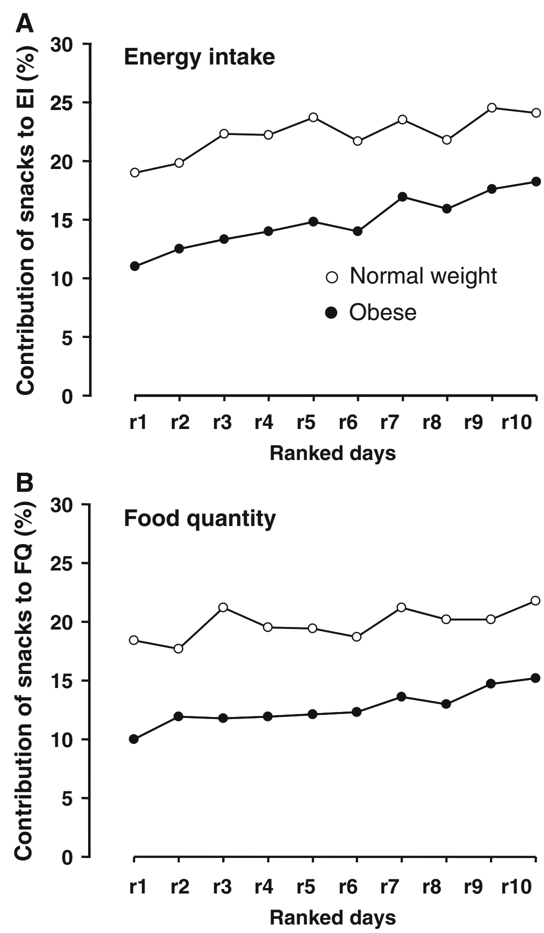

Fig. 3 Relative contribution of snacks to daily energy take (**a**) and food quantity (**b**). *Closed circles* denote obese subjects, *open circles* denote normal weight subjects (mean values)

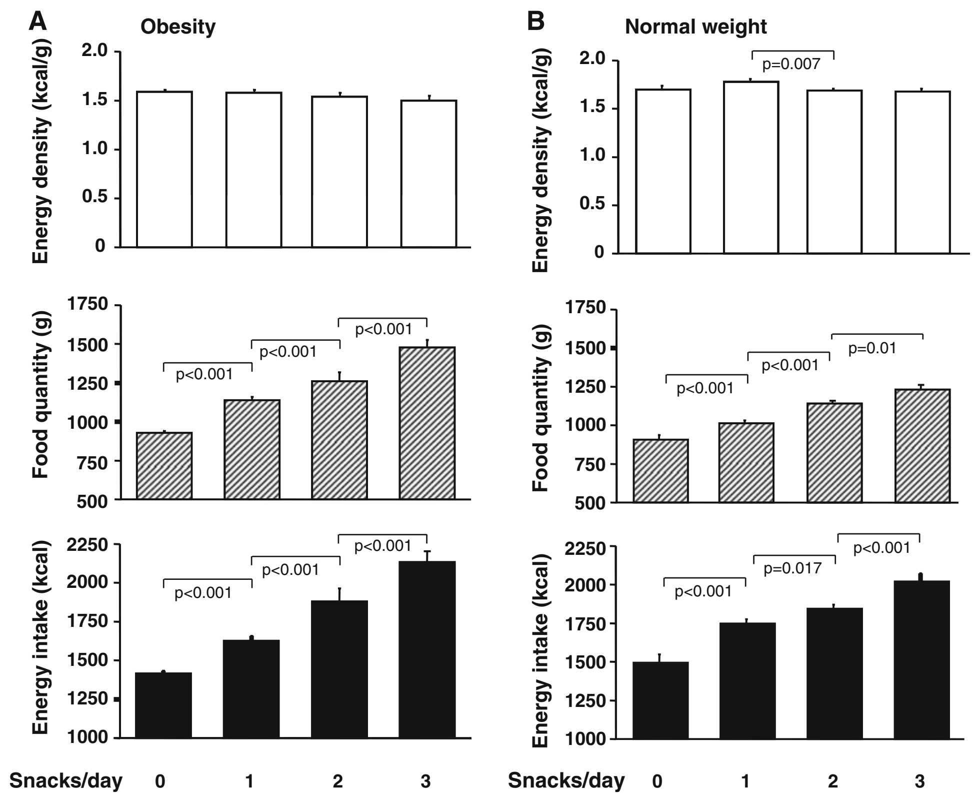

Fig. 4 Contribution of number of snacks to total daily energy intake, food quantity and energy density in 280 obese patients (**a**) and 100 normal weight subjects (**b**) (mean ± SEM)

and (3) differences in the number of meals ingested per day. Under real life conditions it is most likely that a combination of all three factors contributes to alterations of EI which is supported by the present data.

From the perspective of acute hunger/satiety regulation EI depends substantially on the ED of ingested food items since satiety-induced termination of a meal is related to gastric filling and distention and accordingly to meal quantity [10, 27, 28]. In acute feeding experiments the intraindividual FQ required to feel satiated is fairly constant [7–9, 21]. On the other hand, this internal neuroendocrine system of feeding regulation can easily be overridden by cognitive, sensory and social factors which favor an overconsumption beyond the point of feeling comfortably satiated [5, 25, 31, 32]. All these components of regulatory interference can modify meal size which in conjunction with ED has been shown to act independently and synergistically to alter EI under conditions of a laboratory setting [15, 23, 24] The present data demonstrate that during habitual food intake of free living subjects the variation of FQ accounts for two-thirds of the fluctuations of EI while changes of ED account for only one-third.

Moreover, the present study demonstrates that small changes of total daily EI are primarily due to alterations of FQ without significant changes of ED. With greater excursions of daily EI ED becomes increasingly important especially in the obese subjects.

The present data confirm the important role of snacking for EI [1, 11, 14] although one study found no relation at all [26]. The present data are based on an intraindividual comparison thereby excluding interindividual differences of hunger/satiety regulation. The fact that snacks contribute more to EI in normal weight subjects must be considered with caution since our obese subjects are all restraint eaters with a long-standing experience of dieting. The contribution of snacks to daily EI became progressively greater with increasing EI which is in part due to a higher frequency of snacking.

The number of snacks is directly related to daily FQ and EI which is in accord with the experimental evidence that a meal-to-meal compensation for higher EI does not exist [8, 9, 15, 23, 32]. Despite the fact that snacks between main meals are an important contribution to daily EI the present data show that the major reason for the observed short-term variations is the alteration of size and ED of the main meals. Thus, under free living conditions intake of FQ is not as consistent as it could be expected on the basis of hunger/satiety regulation in acute feeding experiments. This reflects most likely the important role of cognitive, sensory and behavioral aspects in the modification of the neuroendocrine mechanisms originating from stomach, hypothalamus and adipose tissue.

Thus, analysis of the eating habits of these free-living populations confirms the role of ED as one important determinant of EI but it also demonstrates that during short-term changes of EI, meal size plays an even greater role in both obese and normal weight subjects.

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