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The Effects of a High-carbohydrate, High-protein or Balanced Lunch upon Later Food Intake and Hunger Ratings

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This study compared the satiating properties of three liquid lunches (450 kcal each), one dominant in protein (71·5% of energy), a second in carbohydrates (99% of energy) and a third containing an equal mixture of the first two formulations, in a within-subjects, repeated measures design. At an *ad libitum* dinner meal, 12 women consumed 31% more kilocalories in the high-carbohydrate lunch condition than in the high-protein lunch condition and 20% more kilocalories than in the mixture lunch condition. Similar results emerged for the amounts of protein and fat ingested at dinner. Subjects also reported significantly greater pre-dinner hunger and excitement about eating in the carbohydrate lunch condition than in the protein lunch condition. Greater enjoyment of dinner was also found after the carbohydrate lunch than after the mixture and protein lunches.

Introduction

High-carbohydrates diets have previously been found to result in self-reports of lower satiety and greater motivation to eat than equicaloric high-protein meals. In a comparison of low-carbohydrate, low-protein, moderate-protein and low-fat diets over a 9 week period, the low-protein diet (containing less than 13% of energy from protein) was found to leave 12 male subjects continually hungry, while the low-carbohydrate diet was ranked the most satiating (Fryer *et al.*, 1955). Using self-report measures of food preference and general motivation to eat, Hill and Blundell (1986) discovered that a high-protein test meal produced ratings of greater fullness and lower desire to eat than a high-carbohydrate test meal of similar weight, flavor and fiber content. Similarly, Vandewater and Vickers (1995) found that high-protein test meals produced greater reports of fullness than low-protein test meals.

Studies using subsequent food intake as a measure of satiety have often found decreased intake after protein ingestion. Booth *et al.* (1970) found that in a supplementary meal 3 h after lunch, eight out of nine subjects ate less after a protein-rich lunch than after a protein-poor one. Teff *et al.* (1989) inferred that a 210 kcal protein pudding was as satiating as a 400 kcal carbohydrate pudding since the two preloads led subjects to consume similar amounts at a later test meal. Intake at an

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evening meal was significantly smaller (12%) after the ingestion of a high-protein meat casserole than after an equicaloric vegetarian casserole at lunch (Barkeling *et al.*, 1990). Moreover, using self-report and subsequent intake measures, Porrini *et al.* (1995) found that whereas food intake was highest after a carbohydrate meal (pasta), a protein meal (meatballs) resulted in the highest fullness and satiety ratings. However, since both Barkeling *et al.* (1990) and Porrini *et al.* (1995) used natural food items that may have varied in taste, texture, masses or appearance, it is difficult to determine which of these variables accounted for the effects upon later food intake. Finally, Huon and Wootton (1991) found that after the ingestion of a high-carbohydrate meal, food intake at an *ad libitum* meal 4 h later was higher than after a low-carbohydrate meal, as were protein intake and self-reported desire to eat. Protein content has been found to correlate positively with indices of satiety (Holt *et al.*, 1995; Porrini *et al.*, 1994), as have energy density, volume, firmness (Porrini *et al.*, 1994), fiber and water content (Holt *et al.*, 1995).

On the other hand, several researchers have found little difference between the effects of protein and carbohydrate upon intake (DeGraaf *et al.* 1992; Johnson & Vickers, 1993; Rolls *et al.*, 1988). However, Johnson and Vickers (1993) point out that they, like Rolls *et al.* (1988) (who also assessed food preferences and pleasantness of a variety of solid foods), deliberately used foods of different sensory qualities and water content in addition to macronutrient composition. Thus, differences in later food intake could be due to any of these factors. Indeed, Hill and Blundell (1986) have stressed the importance of equating meals for caloric density and desirability (perceived pleasantness)—a minimal requirement when different macronutrients form the experimental variable.

The present study offered human subjects three liquid test meals at midday on separate occasions—one high in protein, a second high in carbohydrates and a third solution containing half of each of the two others. It was predicted that subjects would ingest more at an *ad libitum* meal after the high-carbohydrate lunch than after the high-protein or mixed lunches. Previous studies have often found that protein is more satiating by comparing a very high-protein to a very low-protein preload or meal. A mixed solution of 50% high-carbohydrate and 50% high-protein solutions was included to determine whether protein's satiating effects are modified by the addition of carbohydrate. If such a mixture leads to greater satiety than the carbohydrate lunch, this might suggest that protein's satiating effect does not require the absence of carbohydrates and may correspond to the amount of protein eaten.

Method

Subjects

Participants were 12 females from the Yale University student population, recruited through poster advertisements. The mean age of participants was 20·8 years (range = 18–37). Mean body mass index (BMI) was 22·25 (range = 19–29). None of the subjects were diabetic and all indicated willingness to eat any of the foods offered, as determined by an initial phone screening. Four of the participants were vegetarians.

TABLE 1
Weight and nutrient composition of 450-kcal lunches

Lunch type	Weight (g)	Energy (kcal)	Protein (g, % of energy)	CHO (g, % of energy)	Fat (g, % of energy)
High-protein (Promod)	106·1	450	80·4 (71·5%)	10·7 (9·5%)	9·6 (19·2%)
High-carbohydrate (Polycose)	118·4	450	0	113·3 (99%)	0
Promod & Polycose (combined)	53·0 Promod + 59·2 Polycose	450	40·2 (35·7%)	62 (55·1%)	4·8 (9·6%)

Diets

On three different occasions, each subject received three liquid lunches consisting of either primarily carbohydrate, primarily protein or a mixed lunch consisting of 50% of the carbohydrate solution and 50% of the protein solution. All lunches contained 450 kcal and were served in liquid form. Powders were dissolved in 30 ounces of water and tinted with yellow food coloring to maintain a uniform appearance despite the color variation of the powders. The carbohydrate lunch consisted of 111·3 g of carbohydrate found in 118·4 g of Polycose (99% carbohydrate), a non-sweet caloric supplement from Ross laboratories made of glucose polymers derived from controlled hydrolysis of corn starch. The protein lunch consisted of 80·4 g of protein (71·5% of energy), no more than 9·6 g of fat (19·2%), and no more than 10·7 g of carbohydrate (9·5%), found in 106·1 g of ProMod, a protein supplement from Ross laboratories made of whey protein concentrate and soy lecithin. The mixed lunch contained 59·2 g of Polycose and 53·0 g of ProMod, so that half (225 kcal) of its energy was derived from each solution. Polycose and ProMod powders are specifically designed by Ross Laboratories to have no flavor. The liquid solutions looked identical and were virtually flavorless, in accordance with past efforts (e.g. Teff *et al.*, 1989) to equate the physical state of the meals and thus ensure that any differences in response to them could be attributed to their differing physiological effects, rather than any varying taste sensations or cognitive attributions. Weight and nutrient composition of the liquid lunches is shown in Table 1.

Dinners varied as little as possible, and portions of each food type were large enough so that some always remained on buffet plates. Foods were often high in a single macronutrient, so that macronutrient selection could be more easily measured. Nutritional values of foods are shown in Table 1. Foods and nutritional information were provided by the Yale University Dining Hall.

Experimental procedure

Each subject came into the laboratory on three non-consecutive days. In a counterbalanced design, subjects were given the carbohydrate meal on one occasion, the protein meal on another and the mixed meal on a third. Subjects were instructed to maintain exactly the same breakfast and exercise patterns, at the same time, on each of the three mornings. All subjects followed these instructions. On the first day,

TABLE 2

Foods available for selection at dinner and their macronutrient distribution[a]

Food	Weight (in grams)	% kcal from protein	% kcal from carbohydrate	% kcal from fat
Boiled spaghetti	350	12·8	76·1	9·3
Steamed rice	350	8·4	86·2	1·6
Mashed potatoes	500	7·1	74·0	20·7
Teriaki tofu	300	44·5	9·9	44·5
Hamburger patties (3)[b]	240	33·4	0	64·5
Teriaki chicken breasts (3)[b]	320	59·0	13·5	22·9
Scrambled eggs[c]	300	27·2	2·5	68·6
Tuna salad[c]	475	23·7	1·1	79·4
Tomato sauce	150	15·6	76·1	13·2
Butter	28	0	0	100·0
Shortbread cookies	42	5·3	55·5	40·1
Brownies	150	0·7	37·5	62·8
Sweet iced tea	448	0	100·0	0
Iced water	375	—	—	—

[a] Dinner foods and nutritional information were provided by the Yale University Dining Hall.
[b] Offered only to meat-eaters.
[c] Offered only to vegetarians.

however, choices concerning eating breakfast or exercising were up to each subject. Subjects could also choose to schedule lunches for either 12 p.m., 1 p.m. or 2 p.m., with dinner to follow approximately 4·5–4·75 h later, at either 5 p.m., 6 p.m. or 7 p.m. Appointments were scheduled for the same time on all three days. Upon arrival, subjects were told that the purpose of the study was to investigate the enjoyment of eating by subjects of various ages. (In addition, several distracting questions were inserted into the questionnaire filled out after dinner, asking subjects their preferences between solid or liquid meals.)

Subjects then filled out records of any eating and exercise that took place that morning. They were given a liquid meal, instructed to finish it completely, and informed that they were having the equivalent of a normal-sized, healthy lunch. It was requested that subjects not eat again until their scheduled dinner. All subjects complied with these requests. On the second and third day visits, subjects were at this point handed a photocopy of their first or second day's afternoon food and exercise record (these were generally blank, but some subjects did exercise on the three afternoons) as a reminder of the pattern that they should follow again that day. Upon subjects' return at either 5 p.m., 6 p.m. or 7 p.m., they were immediately given a buffet-style dinner in isolation and instructed to eat as much or as little as they liked. Food and drinks were weighed before arrival, and after each dinner session, food intake was calculated by weighing the remains of each food type and subtracting from the original weights. Subjects notified the experimenter when they were finished eating, and time spent on the meal was recorded. Subjects were allowed to determine the time spent eating, since an imposed time restriction might have artificially prolonged or curtailed subjects' food intake.

Subjects were then given a questionnaire assessing their subjective hunger before the meal, enjoyment of dinner and of the liquid lunch earlier that day, satisfaction with the foods presented at dinner, and pre-dinner excitement about eating, on a visual analog scale. Questions included instructions such as "Rate your level of enjoyment of the meal you just ate", "Rate your level of enjoyment of this meal compared with your usual levels of meal enjoyment", and similar instructions to rate satisfaction, pre-meal hunger, excitement about eating, and enjoyment of liquid lunches. Visual analog scales used a 12 cm line anchored at each cm and with labels at the ends (e.g. not at all enjoyable–extremely enjoyable). (Although dinner intake may have affected subjects' later perceptions of hunger, these questions were presented after dinner to prevent subjects' answers from influencing food intake, the more objective and primary measure of satiety used here.) Subjects then filled out food and exercise records for that afternoon and were handed a photocopy of the food and exercise record from the morning with a reminder to repeat the same patterns on the day of their next session. Subjects were also telephoned on the nights before sessions to confirm session times and remind them of the eating and exercise patterns they needed to repeat. Subjects were paid $25 for participating and debriefed about the nature of the experiment.

Data analysis

Statistical analysis of the effects on food intake and hunger ratings was carried out using a repeated measures analysis of variance (ANOVA) with lunch condition as the independent variable. The eta^2 statistic is an index of effect size describing the proportion of total variability attributable to a factor (SPSS Inc.). Individual correlation analyses were performed to assess associations between food intake in the three conditions, reported hunger, excitement about eating, enjoyment and satisfaction; data were obtained as separate correlation coefficients by Pearson's product moment tests.

RESULTS

Dinner food intake

The first set of analyses were designed to look at the differences in intake at dinner across the three lunch conditions (protein, carbohydrate and mixture). An ANOVA revealed a significant effect of condition upon caloric intake, $F(2,22)=3{\cdot}43$, $p \leq 0{\cdot}05$, $eta^2=0{\cdot}24$. The effect of the three lunch conditions upon food intake at dinner is shown in Figure 1.

Simple contrast tests demonstrated that intake at dinner was lower after the protein lunch than after the carbohydrate lunch, $F(1,11)=5{\cdot}42$, $p \leq 0{\cdot}05$, $eta^2=0{\cdot}33$. Subjects also consumed less after the mixture meal than after the carbohydrate meal, $F(1,11)=4{\cdot}26$, $p \leq 0{\cdot}06$, $eta^2=0{\cdot}28$. Mean intake at dinner was also lower after the protein lunch than after the mixture lunch, but this difference did not reach significance.

Figure 2 shows the effects of lunch condition upon protein, fat and carbohydrate intake at dinner (in grams). Differences in protein intake at dinner emerged, $F(2, 22)=6{\cdot}64$, $p \leq 0{\cdot}01$, $eta^2=0{\cdot}38$, with contrasts revealing less intake in the protein condition, $F(1,11)=9{\cdot}13$, $p \leq 0{\cdot}05$, $eta^2=0{\cdot}45$, and mixture conditions, $F(1,11)=4{\cdot}88$, $p \leq 0{\cdot}05$, $eta^2=0{\cdot}31$, than in the carbohydrate condition. No significant effect of condition was found for fat intake at dinner, but contrast tests demonstrated that less fat was consumed at dinner in the protein condition than in the carbohydrate

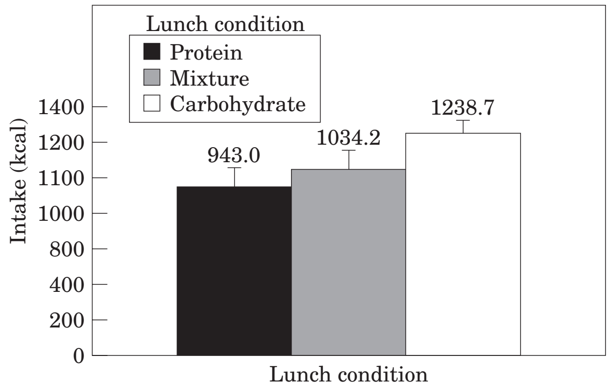

FIGURE 1. Mean (+*SEM*) intake (kcal) at dinner after each experimental lunch condition: protein, mixture, and carbohydrate.

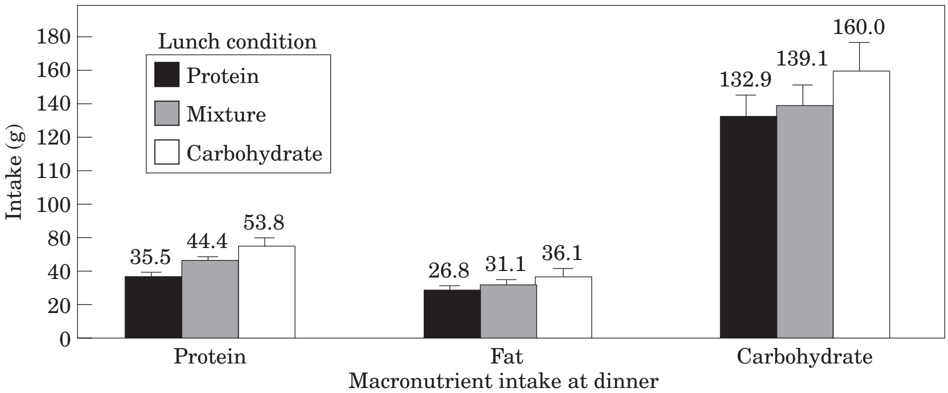

FIGURE 2. Mean (+*SEM*) intake at dinner of protein, fat and carbohydrate (grams) after each experimental lunch condition: protein, mixture and carbohydrate.

condition, $F(1,11)=4{\cdot}70$, $p \leq 0{\cdot}05$, $eta^2=0{\cdot}30$. No significant effects were found for carbohydrate intake at dinner, although a trend emerged where intake was highest in the carbohydrate condition and lowest in the protein condition.

Visual analog ratings: comparisons across conditions

These analyses examined the differences in self-reports of pre-dinner hunger, enjoyment of dinner, satisfaction with the foods presented at dinner and pre-dinner excitement about eating, across the three lunch conditions (protein, carbohydrate and mixture), as shown in Figure 3. Enjoyment of the liquid lunches was also compared across conditions.

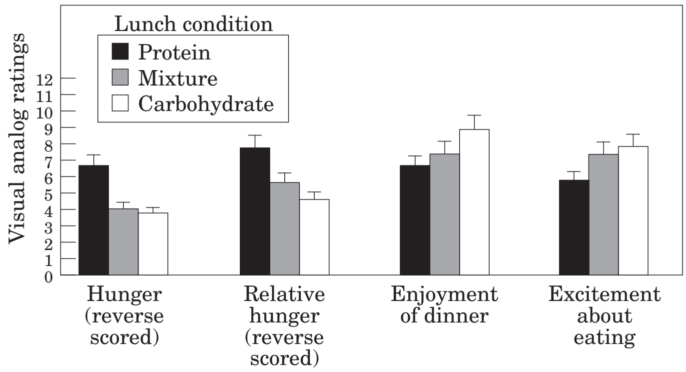

FIGURE 3. Mean (+*SEM*) self-report ratings (filled out after dinner) of pre-dinner hunger (0 = extremely hungry, 12 = not at all hungry), pre-dinner hunger as compared with usual levels before dinner (0 = far greater, 12 = far lower), enjoyment of eating dinner (0 = not at all enjoyable, 12 = extremely enjoyable) and pre-dinner excitement about eating (0 = not at all excited, 12 = extremely excited), after each experimental lunch condition: protein, mixture and carbohydrate.

Repeated measures ANOVA revealed a significant effect of condition upon self-reported hunger before dinner, $F(2,22) = 4{\cdot}06$, $p \leq 0{\cdot}05$, $eta^2 = 0{\cdot}27$. Subsequent tests of within-subject contrasts showed that subjects reported greater hunger after the carbohydrate lunch, $F(1,11) = 4{\cdot}62$, $p \leq 0{\cdot}05$, $eta^2 = 0{\cdot}30$, and after the mixture lunch, $F(1,11) = 5{\cdot}25$, $p \leq 0{\cdot}05$, $eta^2 = 0{\cdot}32$, than after the protein lunch. In addition, hunger levels before the experimental dinner as relative to usual pre-dinner levels also showed a significant effect of condition, $F(1{\cdot}32,\ 14{\cdot}52) = 8{\cdot}67$, $p \leq 0{\cdot}01$, $eta^2 = 0{\cdot}44$. (The Greenhouse-Geisser adjusted *F*-test, yielding higher *p*-values, was used to accommodate a violation of the sphericity assumption.) Contrasts revealed that relative hunger was rated as lower in the protein condition than in the carbohydrate condition, $F(1,11) = 14{\cdot}76$, $p \leq 0{\cdot}005$, $eta^2 = 0{\cdot}57$, and mixture condition, $F(1,11) = 5{\cdot}01$, $p \leq 0{\cdot}05$, $eta^2 = 0{\cdot}31$, and lower in the mixture condition than in the carbohydrate condition, $F(1,11) = 5{\cdot}08$, $p \leq 0{\cdot}05$, $eta^2 = 0{\cdot}32$. Enjoyment of dinner was also significantly affected by condition, $F(2,22) = 8{\cdot}42$, $p \leq 0{\cdot}005$, $eta^2 = 0{\cdot}43$, with the carbohydrate condition yielding higher levels of eating enjoyment than both the protein, $F(1,11) = 11{\cdot}88$, $p \leq 0{\cdot}005$, $eta^2 = 0{\cdot}52$, and mixture conditions, $F(1,11) = 10{\cdot}24$, $p \leq 0{\cdot}01$, $eta^2 = 0{\cdot}48$. Moreover, levels of excitement about eating at dinner varied across conditions, Greenhouse-Geisser adjusted $F(1{\cdot}37,\ 15{\cdot}09) = 4{\cdot}81$, $p \leq 0{\cdot}05$, $eta^2 = 0{\cdot}30$. Excitement levels were greater after the carbohydrate lunch than after the protein lunch, $F(1,11) = 6{\cdot}59$, $p \leq 0{\cdot}05$, $eta^2 = 0{\cdot}38$. No significant differences emerged across conditions for satisfaction with the foods presented at dinner. Finally, there were no differences in enjoyment of the three liquid lunches, $F(2,22) = 0{\cdot}11$, *NS*. This null finding may be due to the flavorless (and thus indistinguishable) nature of the formulas.

Visual analog ratings: associations with food intake

Correlation analyses demonstrated that in the carbohydrate lunch condition, higher reports of satisfaction (reverse scored) after dinner were associated with greater intake at dinner of total calories, $r = -0{\cdot}66$, $p \leq 0{\cdot}05$, and carbohydrate, $r = -0{\cdot}26$, $p \leq 0{\cdot}05$. This was not the case in the protein lunch and mixture lunch conditions, where satisfaction ratings at dinner were independent of the amounts of food or carbohydrate ingested. Also in the carbohydrate lunch condition only, greater pre-dinner excitement about eating (as reported retrospectively after the meal, reverse scored) was associated with higher energy intake, $r = -0{\cdot}64$, $p \leq 0{\cdot}05$, and higher protein intake, $r - 0{\cdot}59$, $p \leq 0{\cdot}05$. In addition, a trend emerged in the carbohydrate lunch condition where ratings of greater hunger before dinner (reverse scored) were associated with greater intake of carbohydrates at dinner, $r = -0{\cdot}27$, $p \leq 0{\cdot}06$.

Discussion

The results of this study demonstrate that the macronutrient composition of a midday meal affects both food intake at dinner and self-reported measures of hunger, enjoyment and excitement about eating. These data support previous findings that the ingestion of higher protein foods can lead to an increase in satiety. Both a high-protein lunch and a balanced lunch led to lower food intake at an evening meal than an equicaloric high-carbohydrate lunch. Protein intake at dinner was also lower after the high-protein lunch than after the high-carbohydrate and balanced lunches; similarly, fat intake was lower after the high-protein lunch than after the high-carbohydrate lunch.

On self-reports of hunger that preceded the evening meal, the high-carbohydrate lunch and mixed lunch led to higher ratings than the high-protein lunch. Both enjoyment of dinner and excitement about eating were higher in the carbohydrate condition than in the protein condition, and enjoyment levels were higher in the carbohydrate condition than in the mixture condition.

In addition, although excitement about eating and satisfaction with dinner were correlated with greater total food intake, protein intake (excitement) and carbohydrate intake (satisfaction) at dinner, these correlations occurred only in the carbohydrate lunch condition (not after the high-protein or mixture lunches). These findings imply that in the carbohydrate condition satisfaction and excitement were closely associated with intake levels, and it may have been necessary for subjects to ingest more in this condition in order to reach higher levels of satisfaction.

Although caloric content, physical characteristics, and volume of the three meals given in this experiment were kept constant, their differential satiating effects may have been influenced by the variation in fat content. Specifically, the protein, mixture and carbohydrate formulations contained 9·6, 4·8 and 0 fat grams, respectively. However, fat has been suggested to be an inefficient appetite suppressant (Blundell & Hill, 1993) and correlates negatively with satiety scores (Holt *et al*., 1995). The delayed satiating effects of fat appear to be too weak to halt overconsumption at later meals (Blundell & MacDiarmid, 1997). Therefore, it is not likely that the greater satiety induced by the protein and mixture solutions would be due to their slightly higher fat content. Future experiments should address the satiating effects of protein while controlling for fat intake.

In the present study, the protein, mixture and carbohydrate lunches induced the greatest to least satiety, respectively. This suggests that adding protein to a meal may increase the level of satiety which follows that meal. This information is useful since natural foods typically contain a combination of macronutrients. However, further study is needed to determine whether protein's effect on satiety is proportional to the amount consumed or whether a certain minimum amount of protein is a requisite for satiety processes to occur.

The findings of the present study support past research that has found protein to reduce later food intake and self-reported hunger more than carbohydrates. This effect may be especially important in individuals who binge eat. It has been suggested that in patients with bulimia nervosa, the insulin release after binge eating on high-carbohydrate foods (Russell *et al*., 1987) and vomiting (Johnson *et al*., 1994) may increase appetite and cause the urge to eat to be perceived as uncontrollable, perpetuating bulimic behavior. The proportion of total energy intake from protein has been found to be lower in these patients than in controls (Hetherington *et al*., 1994). Binge eating episodes consist largely of carbohydrate and fat intake (Van der Ster Wallin *et al*., 1994), often in the form of desserts and snack foods (Rosen *et al*., 1986). Hadigan *et al*. (1989) found that whereas bulimic patients begin binges and meals by consuming dessert and snack foods and spend more time eating these foods during meals, controls begin with meat and fish consumption. This early consumption of high-protein foods by control subjects may lead to increased satiety later on in the course of the meal (Hadigan *et al*., 1989). Patients with binge eating disorder were also found to consume a greater percentage of energy from fat and a lower percentage from protein than controls (Yanovski *et al*., 1992) and a greater percentage from protein and fiber on non-binge days than during binge episodes (Rossiter *et al*., 1992). Further research is needed to establish the distinct satiating efficiency of protein, carbohydrate and fat in these patient populations.

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