

Research and Professional Briefs

Clarifying Concepts about Macronutrients' Effects on Satiation and Satiety

DANA E. GERSTEIN, MPH, RD; GAIL WOODWARD-LOPEZ, MPH, RD; ALEXANDRA E. EVANS, PhD; KRISTINE KELSEY, PhD, RD; ADAM DREWNOWSKI, PhD

ABSTRACT

It seems that many people, including dietetics professionals and other nutrition experts, are unclear about some of the fundamental yet complex concepts behind the influence of dietary macronutrients (ie, protein, carbohydrate, and fat) on appetite regulation. Recent research has begun to unravel some of the more complicated physiological processes of appetite control and regulation generated by hormones such as leptin, ghrelin, and the gut hormone peptide YY3-35. Although the processes by which the macronutrients in our foods influence appetite regulation have been a topic of study for decades, they remain confusing and are often misunderstood. The objective of this article is to define the terminology commonly used to discuss the macronutrients' roles in appetite regulation and to discuss the interrelated concepts and roles of taste, palatability, and energy density.

J Am Diet Assoc. 2004;104:1151-1153.

Appetite is influenced by a multitude of biological, behavioral, and environmental stimuli. To better understand the biological and physiological processes that stimulate and inhibit food consumption, a number of general terms and concepts need to be defined (Figure). The biological drive that impels individuals to search for food is hunger. The feeling of hunger is an important component in determining what, how much, and when to eat (1). When food consumption reduces hunger, physiological processes are stimulated that in-

hibit further eating; this process of feeling full and consequently terminating food consumption during the course of eating is termed satiation. Satiation develops during a meal and tends to bring the period of eating to an end. Satiation (intrameal satiety), therefore, reduces hunger and limits the amount of energy consumed during that meal (1). Satiety (intermeal satiety), on the other hand, develops after foods have been ingested. It is the state of satiety that delays the onset of the next meal and may reduce food consumption at the next eating occasion (1).

The impact of individual macronutrients on satiety is typically measured in experimental studies using a pre-load design. Participants consume preloads differing in energy density (the caloric content of a given weight of food) or in the amount of carbohydrate, protein, or fat, and their energy intakes at the same meal are observed (2). A food that is reported to have high satiety tends to produce a longer intermeal period (a period of time between eating episodes during which an individual does not experience hunger). Alternatively, foods that are reported to have lower satiety tend to produce a shorter intermeal period. Satiety and satiation are distinct but interrelated factors that influence both the type and amount of food consumed (1).

Foods, and more specifically macronutrients, with the same caloric content exert different effects on satiation and satiety independent of their caloric value (1,3). In other words, not all calories are treated equally by the body. In Stubbs and colleagues' review of the energy density of foods (calories/g) (4), they noted that under normal circumstances in which fat contributes disproportionately to energy density, protein, carbohydrate, and fat exert hierarchical effects on satiety in the order of protein > carbohydrate > fat; some additional research has confirmed this phenomenon (5,6). However, one study suggests that this effect is mediated almost exclusively by energy density (7). Although most research has suggested that the macronutrient protein has the most potent action on satiety (5,6,8,9), there is less clear consensus regarding the relative satiety values of carbohydrates and fats. The relative satiety values of these macronutrients (carbohydrates and fats) tend to vary depending on whether the macronutrients are studied in isolation or in foods (10).

Blundell and colleagues (2) found that fats and carbohydrates do not have identical effects on the appetite profile. Their studies, in agreement with those of others (11), showed that high-fat foods have a weak effect on satiation and satiety compared with sucrose. Holt and colleagues (3) calculated satiety index scores by dividing the area under the curve (AUC) for the satiety response to

D. E. Gerstein is an associate specialist and G. Woodward-Lopez is an associate director, Center for Weight and Health, University of California, Berkeley. A. E. Evans is an assistant professor, Norman J. Arnold School of Public Health, Department of Health Promotion, Education and Behavior, University of South Carolina, Columbia. K. Kelsey is a research assistant professor, Center for Development and Learning, University of North Carolina at Chapel Hill. A. Drewnowski is a program director, Center of Public Health Nutrition, University of Washington, Seattle.

Address correspondence to: Dana E. Gerstein, MPH, RD, Center for Weight and Health, University of California, Berkeley, 3 Giannini Hall #3100, Berkeley, CA 94720-3100. E-mail: danaeg@nature.berkeley.edu

Copyright © 2004 by the American Dietetic Association.

0002-8223/04/10407-0009\$30.00/0

doi: 10.1016/j.jada.2004.04.027

Hunger: the biological drive that impels the ingestion of food
Satiation: (intra-meal satiety) the sensation of fullness during an eating episode that contributes to the cessation of eating
Satiety: (intermeal satiety) the sensation of fullness between eating episodes that tends to inhibit the resumption of eating, but is also commonly used to refer to both intra- and inter-meal satiety combined
Satiety index score: a calculated value based on a subject's satiety ratings after consuming various foods
Sensory-specific satiety: the changing hedonic response to the sensory properties of a particular food as it is consumed (eg, the pleasantness of the eaten food decreases significantly more than the pleasantness of the uneaten food)
Energy density: the caloric value of a food per unit weight or volume
Palatability: a subjective measure of a food's pleasantness
Passive over-consumption: a nondeliberate ingestion of excess calories, in which signals for satiation do not function effectively to control meal size

Figure. Glossary of relevant terminology for general concepts of satiation and satiety.

commonly consumed test foods by the study group mean satiety AUC for the satiety response to white bread, in this case, and multiplying by 100. They found that more energy-dense (calorie/g), fat-rich foods had lower satiety index scores, whereas bulky, hydrated foods that were high in protein, fiber, or water content had higher satiety index scores. The sugar, starch, and total carbohydrate content of the foods were not statistically related to the satiety index scores; however, the direction of the relationship with starch was positive. Not all carbohydrates necessarily exert the same effect on intermeal and intra-meal satiety. For example, fiber has consistently been shown to have a higher satiety value when compared with digestible complex carbohydrates and simple sugar (12,13).

Satiety may develop for foods that taste, look, or even feel like previously ingested foods. This is termed sensory-specific satiety. Rolls reviewed several studies that showed this phenomenon, showing that after eating a test meal the pleasantness of the taste, smell, texture, and appearance of the eaten foods decreased significantly more than for the uneaten foods (14). A similar phenomenon was observed by Raben and colleagues; their subjects reported lower desires for something sweet after carbohydrate-rich meals and higher desires for something sweet after protein-rich meals (7). De Castro (8) reported a comparable macronutrient-specific effect whereby consumption of a given macronutrient tended to suppress the intake of that macronutrient for up to 2 days.

TASTE, PALATABILITY, AND ENERGY DENSITY

It is important to keep in mind that individuals do not eat solely based on hunger. Taste is usually the number-one reason given for eating a specific food, and a decrease in good taste is often given as a reason for terminating or reducing food intake (15). Taste and more specifically palatability (a subjective measure of the pleasantness of

food) have consistently been shown to influence food choice (15). Palatability and energy density, which is determined by comparing the food's caloric energy with the food's weight, are inextricably linked (15,16); foods are preferred because they are energy dense. On the other hand, low-energy-dense foods, foods that typically contain more water and less fat, tend to be more satiating but less palatable (15,16). Holt and colleagues (3) found a significant inverse correlation between palatability ratings and satiety index scores, so that the more palatable foods were generally less satiating.

The fact that high-fat foods are more energy dense, have a higher palatability, and have lower intra-meal and intermeal satiety value helps explain why individuals tend to overconsume high-fat foods, a process termed passive over-consumption (1,11). Raben and colleagues (7) compared the effects of protein-rich, carbohydrate-rich, fat-rich, and alcohol-rich meals on satiety while controlling for energy density and fiber and found no independent effect of macronutrient content. Therefore, energy density and fiber content may account for most of the differences in the macronutrients' differential effects on satiety. However, under normal free-living conditions, fat contributes disproportionately to the energy density of the diet (17), and research has shown that when food is unrestricted, gains in body weight are greater when high-fat foods are consumed as compared with low-fat foods (1). Therefore, the hierarchical effect of macronutrients on satiety still has practical significance.

CONCLUSIONS

To create and consume a satisfying diet with high intra-meal and intermeal satiety, we ideally want our diet to consist of low-energy-dense foods with high palatability; however, such foods do not commonly exist. A diet that is rich in low-energy-dense foods would enable individuals to experience a sense of fullness during meals (high meal satiation), would inhibit overconsumption, and would give a sense of extended between-meal satisfaction (high intermeal satiety), so that subsequent hunger and eating are delayed. Such a diet would be low in fat, provide adequate protein and fiber, and include plenty of fruits, vegetables, whole grains, and foods with high water content (naturally or incorporated during preparation) (18).

The dietary recommendations of the American Heart Association, American Dietetic Association, and other agencies have been consistent with these principles for decades. However, the emphasis on specific components of these recommendations has varied as the research has evolved and the needs of the population change, as is the case with the renewed interest in energy density as a key factor in obesity prevention. This process of fine tuning recommendations and more accurately framing the issues does not represent an about-face. Rather, new research has helped us to understand and substantiate, for example, the mechanisms by which high-fat diets tend to lead to excess gains and how other energy-dense foods can have a similar effect.

Unfortunately, foods that are low in fat and energy density, especially the more palatable of these, are typically more costly and/or inconvenient to purchase or prepare. In fact, our current food supply is abundant in low-cost, convenient foods that have high energy density,

high palatability, and low satiety. Thus, one of our greatest challenges as dietetics professionals and nutrition experts is to not only promote the consumption of low-fat, high-fiber, and low-energy-dense foods to the public, but also to work with the food suppliers and producers to make these types of foods as inexpensive and palatable as possible while advertising and packaging them aggressively to increase their appeal and convenience.

The information presented in this article was collected and synthesized as a part of a literature review on the Determinants of Energy Imbalance conducted for the Centers for Disease Control and Prevention (CDC) Special Interests Project 00-07 (SIP-07). The authors acknowledge and thank the CDC as well as the Dean's Office of the College of Natural Resources, University of California, Berkeley, for their financial support.

References

1. Blundell JE, Lawton JR, Cotton JR, Macdiarmid JI. Control of human appetite: Implications for the intake of dietary fat. *Annu Rev Nutr.* 1996;16:285-319.
2. Blundell JE, Burley VJ, Cotton JR, Lawton CL. Dietary fat and the control of energy intake: Evaluating the effects of fat on meal size and postmeal satiety. *Am J Clin Nutr.* 1993;57(suppl):S772-S778.
3. Holt SH, Miller JC, Petocz P, Farmakalidis E. A satiety index of common foods. *Eur J Clin Nutr.* 1995;49:675-690.
4. Stubbs J, Ferres S, Horgan G. Energy density of foods: Effects on energy intake. *Crit Rev Food Sci Nutr.* 2000;40:481-515.
5. Johnstone AM, Stubbs RJ, Harbron CG. Effect of overfeeding macronutrients on day-to-day food intake in man. *Eur J Clin Nutr.* 1996;50:418-430.
6. Blundell JE, Macdiarmid JI. Fat as a risk factor for overconsumption: Satiety, satiety, and patterns of eating. *J Am Diet Assoc.* 1997;97(suppl):S63-S69.
7. Raben A, Agerholm-Larsen L, Flint A, Holst JJ, Astrup A. Meals with similar energy densities but rich in protein, fat, carbohydrate, or alcohol have different effects on energy expenditure and substrate metabolism but not on appetite and energy intake. *Am J Clin Nutr.* 2003;77:91-100.
8. de Castro JM. What are the major correlates of macronutrient selection in Western populations? *Proc Nutr Soc.* 1999;58:755-763.
9. Marmonier C, Chapelot D, Louis-Sylvestre J. Effects of macronutrient content and energy density of snacks consumed in a satiety state on the onset of the next meal. *Appetite.* 2000;43:161-168.
10. Bray GA, Popkin BM. Dietary fat intake does affect obesity! *Am J Clin Nutr.* 1998;68:1157-1173.
11. Green SM, Burley VJ, Blundell JE. Effect of fat- and sucrose-containing foods on the size of eating episodes and energy intake in lean males: Potential for causing overconsumption. *Eur J Clin Nutr.* 1994;48:547-555.
12. Howarth NC, Saltzman E, Roberts SB. Dietary fiber and weight regulation. *Nutr Rev.* 2001;59:129-139.
13. Pereira MA, Ludwig DS. Dietary fiber and body weight regulation. Observations and mechanisms. *Pediatr Clin North Am.* 2001;48:969-980.
14. Rolls BJ. Sensory-specific satiety. *Nutr Rev.* 1986;44:93-101.
15. Nasser J. Taste, food intake and obesity. *Obes Rev.* 2001;2:213-218.
16. Drewnowski A. Energy density, palatability, and satiety: Implications for weight control. *Nutr Rev.* 1998;56:347-357.
17. Yao M, Roberts SB. Dietary energy density and weight regulation. *Nutr Rev.* 2001;59:247-258.
18. Rolls BJ, Bell EA. Dietary approaches to the treatment of obesity. *Med Clin North Am.* 2000;84:401-417.