Dietary Variety, Energy Regulation, and Obesity

Hollie A. Raynor and Leonard H. Epstein
University at Buffalo

Increased variety in the food supply may contribute to the development and maintenance of obesity. Thirty-nine studies examining dietary variety, energy intake, and body composition are reviewed. Animal and human studies show that food consumption increases when there is more variety in a meal or diet and that greater dietary variety is associated with increased body weight and fat. A hypothesized mechanism for these findings is *sensory-specific satiety,* a phenomenon demonstrating greater reductions in hedonic ratings or intake of foods consumed compared with foods not consumed. Nineteen studies documenting change in preference, intake, and hedonic ratings of food after a food has been eaten to satiation in animals and humans are reviewed, and the theory of sensory-specific satiety is examined. The review concludes with the relevance of oral habituation theory as a unifying construct for the effects of variety and sensory-specific satiety, clinical implications of dietary variety and sensory-specific satiety on energy regulation, and suggestions for future research.

The prevalence of obesity in the United States is increasing for adults (Kuczmarski, Flegal, Campbell, & Johnson, 1994) and children (Troiano, Flegal, Kuczmarski, Campbell, & Johnson, 1995). Obesity results from positive energy balance, in which more energy is consumed than expended. One factor that may contribute to overconsumption and the increase in obesity is dietary variety, particularly variety from energy-dense foods (McCrory et al., 1999).

Dietary variety occurs when a meal or diet is composed of foods that differ on at least one sensory characteristic (e.g., color, flavor, shape). Studies have investigated the effect of variety on intake by examining food consumption in single-food or mixed meals, or in single-food diets versus varied meal or cafeteria diets. The review begins by examining research on the effects of varying dietary variety on energy consumption, followed by studies exploring the effects of manipulating dietary variety on anthropometric status.

One hypothesis for the influence of variety versus single-food meals on increased intake and body composition is differential experience with the sensory characteristics of foods in meals and diets containing more variety. This hypothesis has led to research on *sensory-specific satiety* (Hetherington & Rolls, 1996), a phenomenon in which hedonic ratings of a food eaten to satiation decrease more than hedonic ratings of foods not eaten to satiation. We next review studies examining sensory-specific satiety. This body of research tests how sensory characteristics of food influence food consumption, including factors that provide a compar-

ison of the effects of sensory versus nonsensory and nutritional factors, such as energy density or macronutrient composition in food intake. This section concludes with a critical discussion of how sensory-specific satiety influences food consumption.

The effects of variety on intake and the model of sensory-specific satiety are consistent with basic research in animals and humans on habituation (Swithers & Hall, 1994). Research on how habituation to food cues influences intake, and the relevance of habituation theory as a unifying construct for variety and sensory-specific satiety, is then considered. Finally, this article discusses implications of research reviewed for obesity treatment, as well as ideas for research on dietary variety and sensory-specific satiety.

We located articles for this review through computerized searches of social science and biomedical databases (MedLine 1966–1999; PsycINFO 1967–1999) using the key phrases *dietary variety, cafeteria diet, body composition,* and *sensory-specific satiety.* References were also located through cross-references within the articles. Thirty-nine studies were identified that manipulated dietary variety and studied the effects on food intake and/or body composition. The review of research on sensory-specific satiety included 19 studies that documented changes in preference or intake after a food has been eaten to satiation in animals and changes in hedonic ratings of food or intake after a food has been eaten to satiation in normal-weight, nondieting humans. Studies examining which characteristics of food (e.g., nutrient composition, shape, color) affect sensory-specific satiety were included.

Dietary Variety and Food Consumption in Animals

Research on the effects of manipulating dietary variety on food consumption and/or anthropometric status in animals and humans is reviewed in Tables 1 and 2, respectively. Studies were categorized into two groups: those comparing one food versus different food courses and those comparing one food versus a varied meal or cafeteria diet. The tables include a description of participants, number of participants in the study, number of flavors or foods in the investigation, whether the nutrient composition of the foods was controlled, and results. The most common dependent variables

Table 2

Human Studies on Dietary Variety and Energy Regulation

References	Participants	N	No. of flavors–foods	Controlled nutrient composition	Significant effects of variety
	Same food versus different food courses				
Hetherington et al. (1989)	NW, unrestrained F	31	2	No	No effect
B. J. Rolls et al. (1984)	ND, NW M	24	4	No	Greater energy intake
	ND, NW F	24			
B. J. Rolls, Rolls, & Rowe (1982)	ND F	24	3	No	No effect
	ND, F children	24	3	Yes	No effect
B. J. Rolls, Rolls, et al. (1981)	NW M	22	2	No	Greater energy intake in second course
	NW F	2			
B. J. Rolls, Rowe, & Rolls (1982)	ND, NW M–F	24	4	Yes	No effect
	ND, NW M–F	24	3	Yes	Greater energy intake
	ND M–F	24	3	Yes	Greater energy intake
B. J. Rolls, Rowe, et al. (1981)	ND F	36	4	No	Greater amount eaten
	NW M	12	3	No	Greater amount eaten
	NW F	12			
	One food versus cafeteria meal				
Beatty (1982)	Nonobese M	10	3	Yes	Greater amount eaten in F
	Nonobese F	12			
Bellisle & Le Magnen (1980)	NW M	3	5	No	Greater amount eaten
	NW F	7			
Bellisle & Le Magnen (1981)	NW M	3	5	No	Greater amount eaten
	NW F	7			
	Obese F	6			
Berry et al. (1985)	M[a]	65	3	Yes	Greater amount eaten
	F[a]	61			
Pliner et al. (1980)	Obese M	24	3	No	Greater amount eaten
	NW, M dieters	24			
	ND, NW M	24			
Spiegel & Stellar (1990)	Underweight F	9	3	No	Greater amount eaten
	NW F	9			
	Obese F	9			

Note. NW = normal weight; unrestrained = without dietary restraint; F = female; ND = nondieting; M = male.
[a] No history of eating disorders.

be very different. Cafeteria diets are often higher in energy density than chow diets, because of higher levels of dietary fat and sucrose. Some investigators have used an isocafeteria diet, a diet containing a variety of flavors and/or textures with a similar nutrient composition to chow, to control for these compositional differences between the diets. For example, Louis-Sylvestre and colleagues (1984) developed an isocafeteria diet composed of rat, hamster, or rabbit chows in powdered or pelletted forms, flavored with aspartame, vaseline, or chocolate. Animals receiving the isocafeteria diet were given the regular chow diet and three other variations of the chow diet daily. Animals consumed significantly more energy when fed the isocafeteria diet than when fed the control diet. Other investigators observed no differences in energy intake when control animals were fed a constant powdered diet and animals in the variety group were fed the same diet that was altered with a variety of flavors and textures, three variations of which were presented to the animals daily (Naim, Brand, Kare, & Carpenter, 1985). The authors theorized that the difference in the outcomes of these two studies (Louis-Sylvestre et al., 1984; Naim et al., 1985) was due to differences in the variety and nutrient composition of each food in the isocafeteria diet offered by Louis-Sylvestre and colleagues that were not present in the isocafeteria diet offered by Naim and colleagues. However, the study by Naim

et al. has been criticized because the flavors used to create the variety may have been less preferred than the flavor of the control diet (Rogers, 1990).

In summary, these investigations show that dietary variety, introduced through varied meals or a varied diet, induces hyperphagia. Even when dietary composition is controlled for by varying flavors and/or texture of the foods, research suggests increased dietary variety generally increases intake (Clifton et al., 1987; Louis-Sylvestre et al., 1984; Morrison, 1974; Treit et al., 1983).

Dietary Variety and Food Consumption in Humans

When dietary variety in a meal is established by providing different foods in successive courses, humans generally consume more food than in meals in which the same food is offered in the same number of successive courses (see Table 2). For example, B. J. Rolls, van Duijvenvoorde, and Rolls (1984) fed participants four courses, one each of sausages, bread and butter, chocolate dessert, and bananas, or four courses of one of these foods. Participants in the varied four-course meal consumed 44% more food and 60% more energy than those participants receiving the same food for each course. In a similar study, participants con-

sumed significantly more grams of yogurt when provided with three flavors over successive courses as compared with participants provided with the same flavor of yogurt in all courses (B. J. Rolls, Rowe, et al., 1981). Hetherington and colleagues (Hetherington, Rolls, & Burley, 1989) used a different methodology to test sensory-specific satiety. They provided participants with a meal of cheese and crackers and instructed them to eat as much as they wanted. About 1 hr later, participants were given either another meal of cheese and crackers or chocolate confectionary and again instructed to eat as much as they wanted. Although participants ate more in the varied condition during the second meal, the differences were not significant.

When diet composition of the foods served in the differing meal conditions is held constant, increased intake still occurs in the meal offering more variety (B. J. Rolls, Rowe, & Rolls, 1982). In B. J. Rolls, Rowe, and Roll's investigation, participants were provided with meals consisting of cream cheese sandwiches. Variety was established by flavoring the cream cheese with table salt, lemon essence and saccharin, or curry. Participants received the same flavor sandwich (defined as most preferred by the participant) for three successive courses and at a second session received all three flavors, one in each of three successive courses. With diet composition controlled, the variety condition produced an energy intake that was 15% greater than the same flavor condition.

When a variety of foods are presented simultaneously during a meal, hyperphagia results (Beatty, 1982; Bellisle & Le Magnen, 1980, 1981; Berry, Beatty, & Klesges, 1985; Pliner, Polivy, Herman, & Zakalusny, 1980; Spiegel & Stellar, 1990; see Table 2). Meals consisting of different types of sandwiches (e.g., tuna, roast beef, cheese, egg; Spiegel & Stellar, 1990) or snack foods (e.g., pizza, sausage roll, egg roll; Pliner et al., 1980), as compared with meals of just one of these foods, produce significantly more consumption during the meal. When energy density of foods served in these meals is controlled, increased intake in the variety condition is observed (Beatty, 1982; Berry et al., 1985). When participants were served a snack of either a highly liked flavor of ice cream or a variety of flavors of ice cream, with the same energy density across all flavors, female participants (Beatty, 1982) and male and female participants (Berry et al., 1985) consumed significantly more grams of ice cream in the variety than same condition.

However, if the sensory characteristics of foods presented in a meal are too similar, increased consumption may not occur (B. J. Rolls, Rolls, & Rowe, 1982). For example, providing participants with three flavors of yogurt that were similar in color and texture (i.e., cherry, raspberry, and strawberry) over three successive courses did not enhance intake more than one flavor of yogurt provided for all three courses. The failure to find enhancement of intake was observed when variety was defined by three different flavored chocolate candies that were similar in appearance and texture (B. J. Rolls, Rolls, & Rowe, 1982) and four different colored chocolate candies that were identical in taste and shape (B. J. Rolls, Rowe, & Rolls, 1982).

These studies indicate that variety within a meal can increase food consumption in humans. Variety effects on hyperphagia are observed even when energy density (Beatty, 1982; Berry et al., 1985) and macronutrient composition (B. J. Rolls, Rowe, & Rolls, 1982) of the meal are controlled. However, the variety effect

depends in part on varying as many sensory characteristics as possible within the meal (B. J. Rolls, 1986).

Dietary Variety and Anthropometrics

It should not be surprising that if variety produces hyperphagia, it may also produce increases in body weight or body fat. For example, animals fed a cafeteria diet gained more weight or were heavier (Esteve, Refecaas, Fernandez-Lopez, Remesar, & Alemany, 1994; Estornell et al., 1995; Fisler, Lupien, Wood, Bray, & Schemmel, 1987; Gianotti, Roca, & Palou, 1988; Llado, Proenza, Serra, Palou, & Pons, 1991; Louis-Sylvestre et al., 1984; Plucinski, Bruner, Leatherwood, & Eisen, 1984; Prats et al., 1989; Rogers & Blundell, 1984; B. J. Rolls et al., 1980, 1983; Rothwell & Stock, 1979a, 1979b; Sclafani & Springer, 1976; Segues, Salvado, Arola, & Alemany, 1994) and gained or had more body fat (Esteve et al., 1994; Estornell et al., 1995; Llado et al., 1991; Plucinski et al., 1984; Rothwell et al., 1982; Rothwell & Stock, 1979a, 1979b) than those animals fed a control diet of chow. Cafeteria-fed rats have also developed greater amounts of brown adipose tissue as compared with rats fed chow only (Fisler et al., 1987; Gianotti et al., 1988; Himms-Hagen, Triandafillou, & Gwilliam, 1981; Llado et al., 1991; Rothwell et al., 1982, 1983; Tulp, Frink, & Danforth, 1982). The isocafeteria diet developed by Louis-Sylvestre and colleagues also promoted significant body weight gain in rats. However, the isocafeteria diet that was not associated with enhanced intake did not increase body weight (Naim et al., 1985).

Sensory-Specific Satiety

The increased intake associated with greater dietary variety has been proposed to be due to sensory-specific satiety (E. T. Rolls, 1981). Sensory-specific satiety is shown by a reduction in hedonics of a food(s) being consumed, with little change in hedonics of foods not consumed (Sclafani, 1991). The change in hedonics appears to be related to exposure to the sensory qualities of food rather than the postingestive feedback of the food (Sclafani, 1991). As the hedonics of a food decrease, ingestion of that food generally decreases. Given the opportunity to consume foods not previously eaten during that meal should result in greater intake than if participants are provided the opportunity to resume eating foods that they had just consumed (E. T. Rolls, 1981). This enhancement of food consumption when a variety of foods is available may have been evolutionarily advantageous. Eating a variety of foods with differing nutrient composition may prevent nutritional deficiencies (E. T. Rolls, 1981).

There are two important implications for understanding eating behavior based on the sensory-specific satiety paradigm. The sensory-specific satiety paradigm asks participants to consume foods to satiation and then provides access to more foods. The fact that participants eat again, shortly after they have consumed foods to satiation, suggests that satiation is contextually based and is not based on consumption of an absolute amount of calories, macronutrients, or food volume. Second, the labeling of the phenomenon as *sensory-specific satiety* suggests that satiation may be specific to the sensory characteristics of food consumed and not other components of food. This label has guided research that has focused on the influence of sensory characteristics of food on

intake and, also, on possible mechanisms that would relate sensory factors related to food intake.

Sensory-Specific Satiety in Animals

Table 3 describes investigations of sensory-specific satiety in animals and includes a description of animals used in the study, number of animals in the study, between- and within-groups factors, and results. The dependent measure was food choice during extinction tests or behavioral hedonic response. Research has demonstrated that when provided a choice between two food reinforcers during extinction tests following satiation on one of the food reinforcers, animals will choose the food not consumed to satiation, a demonstration of sensory-specific satiety (Balleine & Dickinson, 1998; Colwill & Rescorla, 1985; Dickinson, Campos, Varga, & Balleine, 1996). For example, when rats were trained to receive food pellets and a sweetened solution in an operant chamber and were fed to satiation on one of the reinforcers, during extinction tests the animals had significantly lower rates of responding per minute for the food reinforcer they had been fed to satiation as compared with the food reinforcer that they had not been fed to satiation (Colwill & Rescorla, 1985; Dickinson et al., 1996). Following the extinction test, Colwill and Rescorla conducted a consumption test to examine the specificity of the satiation. They found that following satiation on one of the food reinforcers, the rats ate significantly more pellets of the food reinforcer that had not been fed to satiation as compared with the food reinforcer fed to satiation. The consumption test indicated that even with postingestive feedback, the rats predominately ate the food for which they experienced no sensory stimulation during the trial.

To control for differing postingestive feedback that might occur when composition of the foods provided to the rats was very different, Balleine and Dickinson (1998) provided food reinforcers that were 20% polycose solutions flavored with a 0.1 M sodium chloride solution or 3% lemon juice. Consequently, the reinforcers would provide the same postingestive effect but provide different oropharyngeal stimulation. The rats were trained to receive the two food reinforcers in an operant chamber. After the final training session, the rats were allowed to consume one of the two solutions for 1 hr. Half the rats received the salty solution, and the other half

received the sour solution. Following satiation, an extinction test was conducted. As with the previous studies, the rats performed significantly fewer responses per minute on the lever that in training had delivered the solution that they had been prefed. This study demonstrated that the changes in preference were a consequence of the sensory aspects and not the postingestive feedback of the solution.

Taste reactivity in rats has been used to assess sensory-specific satiety by videotaping reactivity to oral infusions to determine positive hedonic reactions (nonrhythmic lateral tongue profusions, rhythmic midline tongue profusions, and paw licking) and aversive hedonic reactions (gapes, chin rubbing, face washing, forelimb flails, paw treading, and head shaking; Berridge, 1991). Rats consumed an oral infusion of milk or a 0.3 M sucrose solution (both solutions ordinarily elicit strong positive hedonic reactions and were of roughly similar caloric content) until they demonstrated satiation actively (e.g., ejected the fluid from the mouth) or passively (e.g., allowed the solution to drip out of the mouth). One minute after satiation, animals received an infusion of one of the two solutions for 30 s. Positive hedonic reactions to the sucrose solution were significantly reduced if the rat had consumed the sucrose solution to satiation but not if it had recently consumed milk to satiation. Similar outcomes were also found with the milk solution; however, the results were not statistically significant.

In summary, these studies show that after a food is consumed to satiation, preference for that food decreases more than preference to consume the food that has not been ingested. Greater reductions in hedonic response occur following ingestion of a food as compared with a food that was not ingested. These results also show that differential reductions in preference of the food items occurred because of the difference in the sensory attributes of the food rather than from postingestive feedback (Balleine & Dickinson, 1998).

Sensory-Specific Satiety in Humans

Studies investigating sensory-specific satiety in humans generally present participants with small samples of several foods and have participants rate the pleasantness of the taste of the samples. One of the samples is given to participants as a meal, and participants are instructed to eat until they are pleasantly satisfied.

Table 3

Studies Demonstrating Sensory-Specific Satiety in Animals

Reference	Subjects	N	Between-groups factor	Within-group factor	Significant results
Balleine & Dickinson (1998)	F rats	16	Meal flavored with sodium chloride or lemon juice prior to extinction test[a]	None	Greater choice for nonmeal food in extinction test
Berridge (1991)	F rats	11	None	Meal prior to oral infusions	Less hedonic response to oral infusions for sucrose if meal was sucrose
Colwill & Rescorla (1985)	M rats	20	Meal prior to extinction or consumption tests	None	Greater choice for nonmeal food in extinction and consumption test
Dickinson et al. (1996)	M rats	16	Meal prior to extinction test	None	Greater choice for nonmeal food in extinction test

Note. F = female; M = male.
[a] Composition of foods in meals was identical.

Participants then rerate the pleasantness of the food samples at differing time points after the meal (e.g., the time points generally start at 2 min after completion of the meal and can last for as long as 2 hr after the meal). The ratings taken 2 min after completing the meal provide information about immediate changes in palatability that are not greatly influenced by postingestive feedback, whereas the ratings taken 20 min or later after eating provide information about changes in palatability that could be influenced by digestion and metabolic processes.

Studies investigating sensory-specific satiety demonstrated that participants show a significantly larger decline in pleasantness for the food eaten during the meal as compared with the foods that had not been eaten during the meal (Johnson & Vickers, 1992; B. J. Rolls, Rolls, Rowe, & Sweeney, 1981; B. J. Rolls et al., 1984; Vandewater & Vickers, 1996). The decline in pleasantness remained consistent at 2 and 20 min after eating (B. J. Rolls, Rolls, et al., 1981). Table 4 provides information on investigations with a primary aim of documenting differential changes in hedonics in foods eaten and not eaten to satiation. This table, and all subsequent tables, includes a description of participants, number of participants, the primary manipulation of the investigation, and results. Hedonic ratings of foods were the dependent variables in these studies. B. J. Rolls and colleagues (B. J. Rolls, Rolls et al., 1981; B. J. Rolls et al., 1984) also found that food samples with similar sensory characteristics to those of the food eaten during the meal had greater declines in pleasantness than food samples with very different sensory characteristics than those of the food eaten during the meal. For example, B. J. Rolls et al. (1984) classified cheese and crackers, sausages, bread and butter, and potato chips as savory foods, whereas yogurt, chocolate whipped dessert, bananas, and oranges were classified as sweet foods. When a savory food was eaten as a meal, there was a significant decrease in pleasantness ratings of other savory foods with no change in pleasantness of the sweet foods, and when a sweet food was eaten as a meal, there was a significant decrease in pleasantness ratings of the other sweet foods with no change in ratings of the savory foods.

These investigations indicate that after a food has been eaten to satiation, the pleasantness of the taste of that food decreases more so than that of other foods not eaten. In addition, foods that have similar sensory aspects to those of the foods eaten to satiation also have some reduction in palatability, whereas those foods that have very different sensory aspects than those of the food eaten to satiety show no changes in palatability. These changes in hedonic ratings were very rapid, occurring within 2 min of eating a meal and persisting for some time, indicating that the changes in ratings were related more to the specific sensory attributes of the food consumed than the postingestive feedback.

Sensory Characteristics of Food and Sensory-Specific Satiety

Table 5 describes investigations examining food-related sensory stimulation that may affect sensory-specific satiety. Rolls and colleagues (B. J. Rolls, Rowe, & Rolls, 1982) observed significant decreases in the pleasantness of the food eaten in comparison with foods not eaten when foods were chocolate candies varying only in color and pasta varying only in shape. However, when participants were fed cream cheese sandwiches flavored with salt, lemon essence and saccharin, or curry, there were no significant differences in changes of pleasantness ratings of the sandwich eaten as compared with the sandwiches not eaten (B. J. Rolls, Rowe, & Rolls, 1982). It has been generally observed (B. J. Rolls, Rolls, et al., 1981; B. J. Rolls et al., 1984) that intake during ad-lib eating is consistent with decreases in preference observed for sensory-specific satiety. However, in this study a consistent pattern of changes in preference and intake was not observed. Although the pasta meal showed sensory-specific satiety and a greater intake in the variety condition, the candies showed sensory-specific satiety but not increased consumption in the variety condition, whereas the sandwiches showed increased consumption in the variety condition but no sensory-specific satiety.

Guinard and Brun (1998) investigated the contributions of food texture (hard vs. soft) to sensory-specific satiety. They found that pleasantness of the texture of hard foods (sandwich on baguette and apple) decreased significantly more than that of soft foods (sandwich on white bread and applesauce) after consumption of the sandwich on baguette. In addition, pleasantness of texture of soft foods decreased significantly more than that of hard foods after a meal of applesauce was eaten. The results of these investigations indicate that sensory aspects of food related to appearance and mouth feel can be involved in sensory-specific satiety.

Table 4
Studies Demonstrating Sensory-Specific Satiety in Humans

Reference	Participants	N	Assessment of SSS	Significant results
Johnson & Vickers (1992)	M	13	Eight foods, each presented as meal	SSS except for roll
	F	25		
B. J. Rolls et al. (1984)	ND M	24	Eight foods, four presented as meal	SSS, SSS for savory foods, SSS for sweet foods
	ND F	24		
B. J. Rolls, Rolls, et al. (1981)	M	17	Eight foods, each presented as meal	SSS
	F	15		
	M	22	Eight foods, two presented as meal	SSS
	F	2		
Vandewater & Vickers (1996)	M–F	69	Five foods, one presented as meal	SSS

Note. Participants were instructed to rate the hedonic qualities of food samples provided prior to and after a meal. Participants were normal weight unless otherwise indicated. SSS = sensory-specific satiety, such that there was a greater decrease in ratings of meal versus nonmeal food; M = male; F = female; ND = nondieting.

Table 5

Characteristics of Studies Investigating Aspects of Sensory Qualities of Food Affecting Sensory-Specific Satiety

Reference	Participants	N	Sensory manipulation	Significant results
Guinard & Brun (1998)	M	16	Taste (salty–sweet)	SSS for salty, sweet, hard (for meal
	F	16	Texture (hard–soft)	of hard sandwich) and soft foods
				(for meal of applesauce)
B. J. Rolls, Rowe, & Rolls (1982)	ND M–F	24	Color	SSS
	ND M–F	24	Shape	SSS
	ND M–F (not all normal weight)	24	Flavor	No effect

Note. Participants were instructed to rate the hedonic qualities of food samples provided prior to and after a meal. Participants were normal weight unless otherwise indicated. M = male; SSS = sensory-specific satiety, such that there was a greater decrease in ratings of meal versus nonmeal food; F = female; ND = nondieting.

The Influence of Postingestive Feedback on Sensory-Specific Satiety

Effects of Time on Sensory-Specific Satiety

One way to test whether the differential changes in palatability of foods consumed as compared with foods not consumed are affected by postingestive feedback is to examine the effects of time on the changes in palatability. If postingestive feedback is an important factor influencing hedonics and satiety, then changes in hedonics should be related to time required for the food to be digested and absorbed. In a general sense, postingestive feedback should increase after ingestion and then decrease, with the optimal feedback differing as a function of the composition of the meal. Changes in hedonics and satiation should be less pronounced immediately after food consumption because there has not been adequate time for the food to be completely digested and absorbed, and these changes should increase over time and, eventually, decrease. Studies on hedonic changes measured over time in the sensory-specific satiety paradigm are presented in Table 6.

Following a meal of one of the foods, the greatest decline in pleasantness occurred for the food eaten during the meal, and this decrease was greatest 2 min after the meal (Hetherington et al., 1989). Ratings taken at 20, 40, and 60 min after the meal were not significantly lower than the ratings taken 2 min after the meal. These results suggest that the change in the hedonic response in the eaten and uneaten foods did not depend on postingestive feedback;

not enough time had passed in the 2 min after the meal for postingestive feedback to occur in significant amounts. Other investigations have also shown no effect of time on sensory-specific satiety (Birch & Deysher, 1986; Guinard & Brun, 1998; B. J. Rolls, Hetherington, & Burley, 1988a, 1988b; Tepper, 1992).

Energy Density and Sensory-Specific Satiety

If the differential changes in hedonics of a food eaten to satiation as compared with foods not eaten to satiation are greatly influenced by postingestive feedback, then foods that produce less postingestive feedback (e.g., foods low in energy density) should show less changes in palatability after they have been consumed. Consequently, there should be very little differential change in hedonics of low-energy-density foods eaten to satiation as compared with foods not eaten to satiation. Table 7 presents studies investigating the effects of energy density on sensory-specific satiety.

B. J. Rolls, Hetherington, and colleagues (B. J. Rolls et al., 1988a; B. J. Rolls, Hetherington, & Laster, 1988) tested the impact of foods with differing energy densities on changes in hedonics of foods eaten to satiation and foods not eaten to satiation. Test meals of low-calorie (0.07 kcal/g) and high-calorie (0.49 kcal/g) tomato soup or low-calorie (0.09 kcal/g) and high-calorie (0.54 kcal/g) orange Jell-O were given to participants after they had rated the pleasantness of nine food samples (B. J. Rolls et al., 1988a). At 2,

Table 6

Studies Examining Effects of Time on Sensory-Specific Satiety

Reference	Participants	N	Rating times after meal (in minutes)	Significant results
Birch & Deysher (1986)	Preschool children	21	0, 20	SSS, no effect of time
	ND adults	26		
Guinard & Brun (1998)	M	16	2, 20	SSS, no effect of time
	F	16		
Hetherington et al. (1989)	Unrestrained F	31	2, 20, 40, 60	SSS, no effect of time
B. J. Rolls et al. (1988a)	Unrestrained F	24	2, 20, 40, 60	SSS, no effect of time
B. J. Rolls et al. (1988b)	Unrestrained F	10	2, 20, 40, 60, 120	SSS, no effect of time
Tepper (1992)	Restrained and unrestrained M–F	20	2, 20, 40	SSS, no effect of time

Note. Participants were instructed to rate the hedonic qualities of food samples provided prior to and after a meal. Participants were normal weight unless otherwise indicated. SSS = sensory-specific satiety, such that there was a greater decrease in ratings of meal versus nonmeal food; ND = nondieting; M = male; F = female; unrestrained = without dietary restraint; restrained = with dietary restraint.

Table 7
Studies Investigating Energy Density and Sensory-Specific Satiety

Reference	Participants	N	Manipulation	Significant results
Birch & Deysher (1986)	Preschool children	21	High- and low-kcal pudding	SSS, no effect of ED
	ND adults	26		
B. J. Rolls et al. (1988a)	Unrestrained F	24	High- and low-kcal soup or Jell-O	SSS, no effect of ED
B. J. Rolls et al. (1988)	Unrestrained F	32	High- and low-kcal pudding or Jell-O	SSS, no effect of ED

Note. Participants were instructed to rate the hedonic qualities of food samples provided prior to and after a meal. Participants were normal weight unless otherwise indicated. SSS = sensory-specific satiety, such that there was a greater decrease in ratings of meal versus nonmeal food; ND = nondieting; ED = energy density; unrestrained = without dietary restraint; F = female.

20, 40, and 60 min after consuming the test meal, participants rated the food samples again. Results indicated that, as with previous studies, there was a significant difference between the pleasantness ratings of the foods; the pleasantness of the food eaten during the test meal decreased more significantly than that of the uneaten foods. However, although there was a significant difference in caloric intake during the low- and high-calorie conditions, there was no difference between the low- and high-calorie conditions in the changing pleasantness of the food samples over time. When this study was replicated using different test meals (low- and high-calorie strawberry–banana Jell-O and chocolate pudding), similar results were found: A significant difference in caloric intake occurred in the low- and high-calorie conditions, and a differential change in hedonics was found between the foods that were eaten as compared with the foods that were not eaten (B. J. Rolls et al., 1988). The size and the time course of the change in hedonics of the foods eaten as compared with the foods not eaten were not affected by the number of calories consumed.

Birch and Deysher (1986) also found that the energy density of the food consumed during a snack did not affect changes in preferences of rated food samples. In this investigation, adults and preschool-age children tasted six foods and ranked them in order of preference. Participants were then given a low-calorie (32 kcal) or a high-calorie (132 kcal) pudding. Participants completed two additional preference tests; one immediately following consumption of the pudding and one 20 min later. There was a decline in preference for the pudding, but not for the other food samples, and there was no effect of energy density on the preference changes.

These investigations indicate that postingestive feedback related to energy density had no effect on changes in palatability. Foods that were organoleptically similar but were different in energy density, providing differing amounts of postingestive feedback

(e.g., foods low in energy density provided very little or less postingestive feedback than foods high in energy density), had no differential effect on the decline in ratings of the foods eaten as compared with the foods that were not eaten.

Nutrient Composition and Sensory-Specific Satiety

Although energy density does not seem to affect sensory-specific satiety, changes in palatability and subsequent consumption of foods might be differentially influenced by macronutrient composition of foods. Studies investigating the effects of macronutrient composition of foods on sensory-specific satiety (Table 8) indicate that the changes in palatability of foods eaten as compared with foods not eaten was not macronutrient specific (Johnson & Vickers, 1993; B. J. Rolls et al., 1988b). When food samples were matched by flavor or macronutrient type to a preload—for example, a preload of blueberry-flavored whipped cream matched with a food sample of blueberry puree (match for flavor of preload) and a food sample of cream cheese (match for macronutrient composition of preload)—sensory-specific satiety occurred and the drop in liking of the food sample matched for flavor was greater than the drop in rating of the food sample matched for macronutrient composition (Johnson & Vickers, 1993). These outcomes indicate that sensory-specific satiety is related more to the sensory aspects of a food than to the postingestive feedback caused by the macronutrient composition of the food.

In summary, investigations using a variety of approaches determining the effect of postingestive feedback on sensory-specific satiety suggest that sensory-specific satiety is not greatly influenced by postingestive feedback. The differential changes in food palatability of foods consumed as compared with foods not consumed appears within 2 min after eating. These changes occur

Table 8
Studies Examining Effects of Macronutrient Composition on Sensory-Specific Satiety

Reference	Participants	N	Manipulation	Significant results
Johnson & Vickers (1993)	Unrestrained M	6	Meal matched with macronutrient composition or flavor of nonmeal foods	SSS, greater decrease in ratings of nonmeal foods when flavor-matched rather than macronutrient-matched to meal food
	Unrestrained F	8		
B. J. Rolls et al. (1988b)	Unrestrained F	10	Meal matched with macronutrient composition of nonmeal foods	SSS, no effect of macronutrient specificity

Note. Participants were instructed to rate the hedonic qualities of food samples provided prior to and after a meal. Participants were normal weight unless otherwise indicated. Unrestrained = without dietary restraint; M = male; SSS = sensory-specific satiety, such that there was a greater decrease in ratings of meal versus nonmeal food; F = female.

prior to the occurrence of postingestive feedback and do not grow in strength as the amount of postingestive feedback intensifies. Foods with similar sensory properties that have differing energy densities and postingestive feedback show similar changes in hedonics after consumption. Finally, the macronutrient composition of the foods consumed has no effect on the differential changes in hedonics, indicating that nutrient-specific postingestive feedback does not greatly affect sensory-specific satiety.

Sensory-Specific Satiety in Different Modalities

Most investigations of sensory-specific satiety have focused on ratings of the pleasantness of the taste of foods or the desire to eat foods. However, research has also examined sensory-specific satiety across sensory modalities (see Table 9). These investigations have reported that differential changes in pleasantness of a food eaten as compared with foods not eaten do occur in the visual (E. T. Rolls, Rolls, & Rowe, 1983) and olfactory (E. T. Rolls & Rolls, 1997) modalities. E. T. Rolls and Rolls also found that the changes in pleasantness of the smell and taste of a food after that food had been chewed but not swallowed decreased significantly more compared with foods not chewed. In addition, after smelling a food for 5 min, the pleasantness of the smell of the food smelled decreased significantly more than that of a sampling of foods not smelled for 5 min; however, this effect was not as large as when the sampled food was eaten to satiation. These results indicate that change in ratings of the pleasantness of food after exposure to food extends beyond taste to other sensory modalities. The observation of olfactory sensory-specific satiety after chewing, but not swallowing, and smelling foods provides more evidence that sensory-specific satiety does not require postingestive feedback. However, the differential change in hedonics was greater after a food had been eaten to satiation, as compared with chewing or smelling the food for a similar amount of time. These results suggest that sensory-specific satiety does not depend on postingestive feedback, but the greater preabsorptive gastrointestinal stimulation that accompanies eating a food to satiation as compared with oral stimulation only may influence sensory-specific satiety across sensory modalities (E. T. Rolls & Rolls, 1997).

Obesity, Dietary Variety, and Sensory-Specific Satiety

One test of the hypothesis that dietary variety may be a factor in the development of obesity is experimental studies demonstrating increases in weight and body composition in animals provided with a diet of a variety of foods (e.g., cafeteria diet) as compared with a diet of just one food (Esteve et al., 1994; Estornell et al., 1995; Fisler et al., 1987; Gianotti et al., 1988; Llado et al., 1991; Louis-Sylvestre et al., 1984; Plucinski et al., 1984; Prats et al., 1989; Rogers & Blundell, 1984; B. J. Rolls et al., 1980, 1983; Rothwell et al., 1982; Rothwell & Stock, 1979a, 1979b; Sclafani & Springer, 1976; Segues et al., 1994). These studies provide reliable experimental evidence that variety is one factor in the development of obesity.

There are no human studies that have experimentally tested the hypothesis that dietary variety is a factor in the development or maintenance of obesity. However, McCrory and colleagues (McCrory et al., 1999) found that dietary variety was associated with increased intake across 10 food groups, and variety of sweets, snacks, condiments, entrees, and carbohydrates was associated with fatness, whereas a greater variety of fruits and vegetables was associated with lower weights.

There have been three studies evaluating individual differences in sensory-specific satiety and obesity. There are two general ways in which greater food consumption associated with obesity might be related to sensory-specific satiety. First, persons with obesity might show less sensory-specific satiety and, thus, slower decreases in hedonics and more intake than persons who are not obese. On the other hand, an increased intake could be observed if persons with obesity show greater sensory-specific satiety, which might be related to an increased motivation to consume multiple foods when provided a large variety of foods. Sensory-specific satiety for normal-weight dieters and nondieters, dieters with obesity, normal-weight individuals with bulimia, and individuals with anorexia were compared in two experiments (Hetherington & Rolls, 1989). In the first experiment participants were provided low-fat cottage cheese or low- and high-fat cheese on a cracker for a first course and cottage cheese and low- or high-fat foods in a second course. Similar rates of sensory-specific satiety were shown for all groups of participants except those with bulimia. In

Table 9

Characteristics of Studies Demonstrating Sensory-Specific Satiety in Different Modalities

Reference	Participants	N	Sensory modality	Significant results
E. T. Rolls & Rolls (1997)	ND M	9	Smell and taste	Greater decrease in ratings of smell or taste of food chewed–eaten to satiety as compared with foods not chewed–eaten to satiety
	ND F	3		
	ND M	9	Smell and taste	Greater decrease in ratings of smell of food smelled for 5 min or eaten to satiety as compared with foods not smelled or eaten to satiety; greater decrease in ratings of taste of food eaten to satiety as compared with foods not eaten to satiety; no effect of smelling a food for 5 min on changes in rating of taste
	ND F	3		
E. T. Rolls et al. (1983)	ND M	12	Sight	Greater decrease in ratings of the sight of a food eaten to satiety as compared with foods not eaten to satiety
	ND F	12		

Note. Ratings are for hedonic qualities of food. Participants were normal weight unless otherwise indicated. ND = nondieting; M = male; F = female.

a second experiment, participants were provided a low-fat cottage cheese first course and then ad-lib access to cottage cheese in the second course. Results showed sensory-specific satiety for normal-weight nondieters and participants with anorexia. When under-weight, normal-weight, and obese female participants were pro-vided a first meal of one of several sandwiches and then ad-lib access to all the sandwiches in the second meal, similar degrees of sensory-specific satiety were shown for all participants (Spiegel & Stellar, 1990). These data provide limited support for individual differences in sensory-specific satiety between obese and nono-bese participants.

However, there is an important methodological consideration in the sensory-specific satiety paradigm that may make comparison across obese and nonobese participants difficult. In the usual paradigm participants are asked to eat until full in the first course. Because participants who are obese are obese because they con-sume more food than participants who are not obese, they may also consume more food in the first course than participants who are not obese, providing differential sensory experience with the food. These differences in sensory experience in the first course may limit the extent to which changes in the sensory characteristics of foods elicit a shift in hedonic experience. The only way to control for that would be to have participants consume the same amount of food in the first course and compare this to another session in which the first course is a fixed amount of food based on body weight (e.g., a specified number of calories per kilogram of body weight). This would allow a comparison between similar sensory and satiation experiences.

Criticisms of Sensory-Specific Satiety

There have been many investigations documenting a reduc-tion in hedonic ratings of food as the food is eaten to satiation. There are questions regarding the importance of this phenom-enon in the development of satiation. Sensory-specific satiety proposes that the palatability or the pleasantness of food plays a central role in satiation. Research regarding sensory-specific satiety implies that it is the relative level of pleasantness of food, rather than the absolute level, that is important in guiding food consumption (Blundell & Rogers, 1991). Consequently, in a sensory-specific satiety paradigm, a food eaten in the first course of a meal and showing a large reduction in pleasantness ratings, but still having a high overall pleasantness rating, would not cause an increase in consumption if it was offered in the second course. However, a food not eaten in the first course and showing very little reduction in pleasantness ratings with a moderate overall pleasantness rating would cause an increase in consumption if it was offered in the second course. Conse-quently, although the absolute level of pleasantness may still be higher for the food eaten in the first course, there has been a much greater change in the relative level of pleasantness for this food, and it is this greater change in the relative level of the pleasantness of a food that appears to be important in sensory-specific satiety.

It has been suggested that the reason that the relative, rather than absolute, level of pleasantness is important in sensory-specific satiety is that the hedonic measures used in the sensory-specific paradigm are measuring more than just the pleasantness of the taste of the food (Blundell & Rogers, 1991). The change

in the hedonic ratings may be caused by a reduction in the pleasantness of eating the food (e.g., a decrease in appetite) rather than a reduction in the pleasantness of the taste of the food (Blundell & Rogers, 1991). As noted by Mela and Rogers (1998), measures of hunger and food pleasantness are highly associated, indicating that, potentially, participants are rating a decrease in appetite as a decrease in the pleasantness of the taste of the food. It has been recommended that studies could resolve this potential problem by asking participants to rate separately the pleasantness of the taste of the food and how pleasant it would be to eat the food (Blundell & Rogers, 1991). A study using this procedure did find that participants eating a meal of cheese sandwiches showed large reductions in their ratings of the pleasantness of eating the sandwiches, whereas ratings of the pleasantness of the taste of the sandwiches showed much smaller decreases, occurring only in the last third of the meal (Mela & Rogers, 1998).

Studies regarding taste reactivity provide evidence that sug-gests that food reward contains two functional components: "liking" (pleasure) and "wanting" (appetite; Berridge, 1996). These systems appear to have different neural substrates. Food reward pertaining to liking involves opioid and GABA–benzodiazepine neurotransmitter systems, whereas food reward pertaining to wanting involves dopamine systems (Berridge, 1996). Although research indicates that these two systems are indeed separate, as previously suggested, the psychological components of liking and wanting may exist without awareness, causing the core neurological processes of food reward involv-ing liking and wanting to be distinct from the subjective report or even human awareness of these two processes (Berridge, 1996). Consequently, although research shows these systems are separate, differential changes in these systems may occur without conscious awareness and generally appear to be expe-rienced as an integration of these processes (Berridge, 1996), suggesting that subjective measures of liking and wanting may be difficult to accurately assess separately and should be highly correlated. Therefore, making a fine distinction between liking and wanting and trying to assess for these differences could be very difficult and produce a biased outcome. This difficulty in making this distinction may be one of the reasons for the different outcomes in two studies assessing subjective reasons for meal termination (Hetherington, 1996; Mook & Votaw, 1992). Hetherington found that the most common reason given for stopping eating a meal was getting tired of the food (e.g., changes in liking of the food), whereas Mook and Votaw reported that when participants were asked to recall why they stop eating, a feeling of fullness (e.g., changes in wanting of the food) was the most common answer.

It has been proposed (Blundell & Rogers, 1991; Mela & Rogers, 1998) that the initial exposure to sensory characteristics of a new food should be viewed as a method to stimulate eating (e.g., sensitization) rather than being an important factor of satiation. Consequently, exposure to new foods (e.g., greater variety) should prolong or renew eating; the pleasantness of these foods has not decreased because of prior consumption (Blundell & Rogers, 1991). Exposure to novel food stimuli has been shown to increase the desire to eat and consumption of food in satiated participants

(Cornell, Roding, & Weingarten, 1989). Blundell and Rogers argued that the relationship between increased dietary variety and an increase in food consumption could be a function of greater stimulation, thereby increasing consummatory behavior.

Smith (1996) integrated the stimulating and inhibiting effects of exposure to the sensory characteristics of food on eating by suggesting that sensory characteristics of food may provide positive and negative feedback for eating through orosensory stimulation of the preabsorptive receptors along the gastrointestinal tract that are sensitive to the chemical, colligative, or mechanical stimuli of food. As eating ensues, positive feedback dominates the system, causing eating to increase. As more stimulation occurs, negative feedback increases in strength, until the potencies of the positive and negative feedbacks are equal, causing eating to decrease. This theory, again, supports the idea that sensory characteristics of food are important for promoting and inhibiting eating: A variety of sensory characteristics increases the amount of positive feedback in the system, and as exposure to sensory characteristics continues, negative feedback accrues. Greater dietary variety or introduction of new foods into a meal may increase the amount of time required to balance the positive and negative feedback, causing a longer, and larger, eating bout.

Habituation as a Theoretical Model for Variety Effects on Intake

Consuming foods that have a variety of smells, flavors, textures, or shapes provides a different sensory experience than consuming one food. Consuming a variety of foods during a meal changes the sensory experience, whereas consuming one food during a meal provides a constant sensory experience. One theoretical model that may be relevant for understanding the role of varied sensory experiences is *habituation* (Hetherington & Rolls, 1996), a behavioral phenomenon in which repeated presentation of a stimulus results in a decrease in response to that stimulus. The decrease in responding to a repeated stimulus is not, in and of itself, evidence of habituation, because other nonpsychological explanations, such as fatigue (Hetherington, 1996), may explain the change in responding. The primary test for habituation is whether presentation of a novel stimulus after habituation can be used to reinstate responding. If the novel stimulus, or dishabituator, results in an increase in response to the habituating stimulus, then the changes are considered to be learned, rather than a result of fatigue. Epstein and colleagues (Epstein, Caggiula, Rodefer, Wisniewski, & Mitchell, 1993; Epstein, Rodefer, Wisniewski, & Caggiula, 1992) have shown that the salivary and hedonic response to a repeated food cue will habituate and that presentation of a novel food cue results in recovery of the response to the habituating stimulus.

Research based on habituation theory also has shown that eating will resume after a subject has habituated to repeated food stimulus presentations in animals (Swithers-Mulvey & Hall, 1992; Swithers-Mulvey, Miller, & Hall, 1991) and humans (Wisniewski, Epstein, & Caggiula, 1992) if a new stimulus is presented. For example, after experiencing an oral habituation session, rat pups were allowed to consume a diet infused continuously into their mouths for 4 min (Swithers-Mulvey & Hall, 1992). Those pups that were given the same flavor during the oral infusion as in the oral habituation session consumed significantly less than those given a different flavor during the oral infusion. Similar findings

were reported with humans (Wisniewski et al., 1992). In humans, repeated 150-calorie courses of pizza or cheeseburgers were eaten until satiation and salivary habituation occurred. An additional 450-kcal final course of the same or a different food was then presented to participants. Participants consumed a significantly greater number of calories when given the new food as compared with when given the same food during the final course.

Another way to examine the specificity of response decrement to specific stimuli is to compare rates of habituation for participants who are given repeated presentations of the same stimulus versus varied stimuli. Participants given repeated presentations of the same food versus different foods showed greater habituation of the salivary response in the same food as compared with different food condition (Epstein, Paluch, Smith, & Sayette, 1997). Swithers-Mulvey and colleagues (1991) found that oral responsiveness in rat pups was also stimulus specific. In this investigation, two groups of rat pups were given the same flavored oral infusion in the first half of testing. Mouthing response decreased over time in both groups. In the second half of testing, one group was given a different flavored oral infusion. Mouthing response increased in the group given the different infusion but continued to decrease in the group given the same flavored oral infusion.

Two studies have tested whether macronutrient composition of foods influences habituation. In the first study participants were provided high- or low-carbohydrate versions of lemon Jell-O and showed the same patterns of habituation, hedonics, and hunger, independent of the calorie differences (Epstein et al., 1993). In a second study participants were randomized into four groups that varied in the fat and carbohydrate content of yogurts as habituating stimuli. Yogurt stimuli were presented until participants reported satiation. Results showed no effect of carbohydrates on habituation, but the high-fat yogurts did produce more rapid habituation, though greater caloric intake was observed in those provided high-fat yogurts, because of the greater energy density (Myers & Epstein, 1997).

Habituation theory is able to provide a theoretical basis for the increased intake due to variety, which is consistent with slower habituation to sensory responses to varied food cues than the same food cue (Epstein et al., 1997). Likewise, habituation theory provides a mechanism to understand how repeated food cues presented during eating can result in a decrease in food-related responses such as hedonics (Epstein et al., 1992; Wisniewski et al., 1992), salivation (Epstein et al., 1992, 1997; Wisniewski et al., 1992), and mouthing (Swithers & Hall, 1994) and how a change in food cues will result in recovery of those responses, as well as a resumption of eating (Swithers & Hall, 1994; Wisniewski et al., 1992). Habituation theory represents a general theory that focuses on how organisms learn to respond to repeated sensory stimuli, but it is not specific to food stimuli or eating. The variety and sensory-specific satiety paradigms focus on differences in the sensory characteristics of food as ways to influence satiation and intake.

Basic research on the neurophysiology of sensory-specific satiety provides additional support for habituation as the underlying mechanism. E. T. Rolls and colleagues have completed a series of studies with primates that has involved presentation of repeated food cues, with measurement of behavioral response to eat the food, as well as single-cell recordings in different areas of the brain to localize the neurophysiological changes. Animals consume food until there is behavioral evidence of satiety, and then they are

provided the same or different foods. An increase in behavioral response to the new food would be evidence for sensory-specific satiety. Changes in brain activity provide ideas about the biological basis for sensory-specific satiety. Primates who consume a food to satiation show decreases in responses of single cells in the hypothalamus (E. T. Rolls, Murzi, Yaxley, Thorpe, & Simpson, 1986) and orbitofrontal cortex (Critchley & Rolls, 1996; E. T. Rolls, Critchley, Browning, Hernadi, & Lenard, 1999; E. T. Rolls, Sienkiewicz, & Yaxley, 1989), and after a new food is provided, the level of activity in these cells recovers. These data are very consistent with habituation theory and demonstrate that the decrement in responding at the single-cell level is not evidence of fatigue. The decrease in brain activity and recovery on presentation of a new food does not occur for cells in the nucleus of the solitary tract (Yaxley, Rolls, Sienkiewicz, & Scott, 1985), insular gustatory cortex (Yaxley, Rolls, & Sienkiewicz, 1988), or opercular gustatory cortex (E. T. Rolls, Scott, Sienkiewicz, & Yaxley, 1988). Responding of cells in these sensory areas is maintained even as the animals begin to reject food, suggesting that sensory information is transmitted through these pathways but that interpretation of this information changes in the hypothalamus (E. T. Rolls et al., 1986) or orbitofrontal cortex (Critchley & Rolls, 1996; E. T. Rolls et al., 1989, 1999).

The focus of the research on habituation and intake has been on *short-term habituation,* or habituation that occurs when stimuli are repeated within sessions. This model may be relevant for understanding short-term changes that occur within a specific eating bout. The effects of dietary variety can be observed when comparisons are made between consumption in a nonvariety meal or eating bout and consumption in a variety meal or eating bout. During an eating bout, habituation may occur more slowly in the variety meal; consequently, more food is consumed in the eating bout containing variety. Animal research suggests that the effects of variety may also be long-term; diets containing more variety show greater intake over time than diets containing one food (Estornell et al., 1995; Prats et al., 1989; Rogers & Blundell, 1984; B. J. Rolls et al., 1983; Rothwell et al., 1982, 1983; Rothwell & Stock, 1979a, 1982). Habituation can also be observed across sessions, termed *long-term habituation.* Long-term habituation of a variety of responses has been observed in humans (Ornitz & Guthrie, 1989; Packer & Siddle, 1987; Plaud, Gaither, Henderson, & Devitt, 1997), and long-term habituation can occur independently of short-term habituation within sessions (Ornitz & Guthrie, 1989). The repetition of food cues across sessions provides for the opportunity for change in responding within meals over time. One pattern that can be observed is long-term habituation, in which there is a general reduction of response amplitude. Alternatively, based on the characteristics of the stimuli or the scheduling of the stimuli, *long-term sensitization,* or an increase in response to the same stimulus over time, can be observed (Haerich, 1997; Ornitz & Guthrie, 1989; Packer & Siddle, 1987; Plaud et al., 1997). Although habituation provides a model for reduction in food intake over time, the observation that sensitization to repeated food stimuli can also occur opens up ways to better understand why food may increase in value over time, as well as to better understand individual differences in response to repeated food cues over days.

Habituation provides a model to help explain why people would respond differently to varied food cues versus the same food cues,

and this patterning of responses to environmental changes is adaptive in many other response systems. Habituation research also shows that habituation depends on sensory changes but that feedback from other sources can influence the rate of habituation (Swithers-Mulvey & Hall, 1993). One advantage to the organism for habituating to food cues is to promote intake of a variety of foods. Habituation is ubiquitous and is observed at multiple levels from the individual neuron to integrated behavior (Gale & Edwards, 1986). Habituation is present at birth (Zelazo, Brody, & Chaika, 1984), and habituation paradigms represent one of the major methods to explore infant cognition and development (Bornstein & Mayes, 1991). Paradoxically, it would be most advantageous to the organism not to habituate to sensory cues associated with intake during the first few months of life when the food source is very limited, but to begin to show habituation for food cues after weaning. Although there has been some evidence that there are possible developmental changes in habituation (e.g., exploratory behavior in animals; Williams, Hamilton, & Carlton, 1975), research has not been conducted to investigate developmental changes in habituation regarding sensory cues that are associated with eating. Interestingly, early experiences with smells associated with the breast and the nipple do not habituate but are critical for development of preferences (Mennella & Beauchamp, 1996). However, experience with a flavor reduces the choice of that flavor during weaning (Mennella & Beauchamp, 1999), which occurs at a time when habituation would be more adaptive, and might then be responsible in part for choice of a variety of foods.

One of the hypotheses that has been addressed for sensory-specific satiety is that there must be a certain degree of difference between the foods, and presumably, the sensory characteristics of the foods must be discriminable. Changing flavor by introducing variety usually, but not always (B. J. Rolls, Rowe, & Rolls, 1982), enhances food intake. Shifts in attention and habituation to food cues may provide an objective index for the extent to which changes in food will result in hyperphagia.

Research on habituation has also begun to study individual differences in rate of habituation in participants with obesity and bulimia. If habituation is in part responsible for satiation, it would be predicted that participants with obesity should habituate at slower rates than participants who are not obese, which is what we observed (Epstein, Paluch, & Coleman, 1996). In addition, if binge eating in patients with bulimia is in part due to the failure to habituate to food cues, then it would be predicted that patients with bulimia would habituate at slower rates to repeated food cues than patients who do not have bulimia. We found that repeated food presentations in participants with bulimia were associated with a desire to binge and a failure to show a decrease in salivation over repeated food presentations, whereas participants who did not have bulimia showed a decrease in salivation after repeated food presentations (Wisniewski, Epstein, Marcus, & Kaye, 1997).

Motivated behaviors, such as feeding, often increase in response to initial contact with a new stimulus (sensitization) and then begin to decrease (habituation) as contact with the stimulus continues (McSweeney & Swindell, 1999). There are reliable shifts in responding for food within an eating session, which may be related to motivation to eat (McSweeney, Hinson, & Cannon, 1996). Variety in a meal provides for the opportunity of multiple reinforcers, and summation of reinforcer satiation for each food item should enhance intake relative to reinforcer satiation for one rein-

forcer. It is relevant that the neurophysiological basis for sensory-specific satiety can be understood in terms of shifts in motivation for new foods versus foods consumed (E. T. Rolls et al., 1988; Yaxley et al., 1988).

McSweeney and colleagues (1996) argued that these shifts in responding to obtain food during an eating bout are analogous to the pattern of habituation that is observed during repeated presentation of food during a meal. In fact, just as changes in food cues after habituation occurs can reestablish responding (Epstein et al., 1992; Swithers & Hall, 1994), changes in types of food reinforcers can reestablish responding in animals (Melville, Rue, Rybiski, & Weatherly, 1997) and humans (Myers & Epstein, 2000) who are satiated. The patterns of responding for food are not related to caloric density of the reinforcer (Roll, McSweeney, Johnson, & Weatherly, 1995), similar to research on habituation (Epstein et al., 1993) and sensory-specific satiety (B. J. Rolls et al., 1988). McSweeney and Roll (1998) argued that systematic reductions in responding for food during an eating session fit habituation theory better than the satiation hypothesis used in reinforcement theory, thus uniting two important theoretical approaches that may prove useful in understanding why food variety or changing sensory characteristics of food influence intake.

Discussion

There is a large amount of research, replicated in many experimental settings, documenting the relationship between dietary variety, energy intake, and anthropometric status. This body of research suggests dietary variety increases intake, and in animals, the hyperphagia associated with dietary variety composed of highly palatable, energy-dense foods generally also causes an increase in weight and body fat.

Sensory-specific satiety may be the procedure through which a greater variety of foods is associated with increased intake. Research on sensory-specific satiety implicates sensory characteristics of food, factors related to the taste and mouth feel of food, as important determinants in the process of satiation. This research indicates that reductions in hedonic appraisal of foods due to exposure to the sensory characteristics of foods play a role in eating termination. The differential hedonic change to foods eaten as compared with those foods not eaten causes satiation to occur only for those foods that have been eaten; consequently, when a greater variety of food is available during a meal, it may take longer for satiation to occur for all foods, allowing for a greater intake.

These results suggest that a reduction in dietary variety of highly palatable, energy-dense foods may be useful in the treatment and prevention of obesity. Limiting the number of different highly palatable, energy-dense foods in a meal may help reduce energy intake within a meal, thereby reducing overall intake. Research on sensory-specific satiety would also suggest that meals composed of foods with similar sensory qualities (e.g., taste, shape, color) may reduce intake within a meal. When meals and snacks are composed of sensorially similar foods, hedonic ratings of all foods within the meal should drop fairly rapidly, regardless of the food that is being eaten. This should cause the meal to end more rapidly than a meal composed of foods with different sensory qualities. The more rapid reduction in hedonic ratings of all foods in the meal would cause less overall food to be consumed within the

meal, thereby allowing fewer calories to be consumed. It is possible that if reducing variety was enough to reduce intake sufficiently to lose weight, it might be possible not to use the traditional components of obesity treatment, such as self-monitoring or dietary restrictions, as part of obesity treatment. It might be much easier to adhere to a very limited behavioral guideline than the combination of behavioral skills that accompany usual attempts at weight regulation.

On the other hand, implementation of these ideas may provide some of the same challenges to dietary adherence as modifying other aspects of the diet for persons with obesity. Limiting the number of energy-dense foods in the diet may be difficult for Americans as the number of energy-dense sweets and snack foods in the U.S. food market has increased tremendously over the past 30 years (Gallo, 1997). Interestingly, the rise in the prevalence of obesity closely follows the increased variety of these food products (McCrory et al., 1999). Research is needed to develop and test approaches to obesity treatment that use research on variety and sensory-specific satiety as the primary or adjunctive aspects of treatment.

Many questions remain regarding dietary variety, sensory-specific satiety, and their effect on energy regulation. We focus on three areas of interest for human food intake: the effects of dietary variety on long-term energy regulation in humans, the importance of palatability and/or energy density in the relationship between increased variety and consumption, and the amount of sensory exposure to a food required for sensory-specific satiety to occur. Research conducted in these areas could provide valuable information regarding how dietary variety and sensory-specific satiety affect eating termination and energy regulation. Research is needed on the basic physiological mechanisms (E. T. Rolls, 1984) and theoretical mechanisms for variety and sensory-specific satiety (Hetherington & Rolls, 1996; Swithers & Hall, 1994), but we do not address specifics of this research agenda.

Animal and human research has shown that when a variety of foods are provided during an eating bout, there is an increase in consumption of food. Animal research has also provided data on constant versus varied diets and has shown that the effects persist over time and that the hyperphagia is related to changes in body composition and obesity. With humans, there is little experimental research on the effects of dietary variety on long-term energy regulation or body composition. Cabanac and Rabe (1976) did find that 4 participants fed only a vanilla-flavored liquid diet for 3 weeks lost an average of 3.13 kg, and Schutz and Pilgrim (1958) reported a significant reduction in food intake in men fed the same four daily menus, consisting of a total of only 41 foods, over 35 days. Also, refugees in an Ethiopian refugee camp who had extensive experience with very limited foods showed a reduction in food palatability for those foods (E. T. Rolls & deWaal, 1985). These results suggest that less variety in the diet reduces energy intake, producing weight loss.

Research investigating the relationship between dietary variety and increased intake has predominantly used highly palatable, energy-dense foods. It is unknown if the type of food—highlypalatable versus moderately palatable, and/or high-energy-dense foods versus low-energy-dense foods—providing the variety is important in influencing energy intake and/or energy regulation. The failure to find a variety effect (Naim et al., 1985) has been

attributed to the use of low-preference foods in the variety condition (Rogers, 1990).

A cross-sectional study by McCrory and colleagues (McCrory et al., 1999) indicated that a diet varied in high-energy-dense foods, but with limited variety in low-energy-dense foods (e.g., vegetables), was associated with increased energy intake and body fatness, whereas a diet with a larger variety in vegetables than in high-energy-dense foods was associated with decreased energy intake and decreased body fatness. These results suggest that variety in all food groups is not associated with increased body fat, but variety within specific food groups (e.g., sweets, snacks), foods that are generally energy dense and highly palatable, may produce hyperphagia. In addition, this investigation indicates that variety in intake of vegetables, foods that are generally low in energy density and in palatability, may be protective against the development of obesity. Again, it is unclear from this investigation if the relationship between variety and increased intake and body fat is due to energy density or palatability. This is an important relationship to clarify; the food supply continues to increase in the number of modified foods, and these foods are often high in palatability, but maybe are lower in energy density as compared with their non-modified counterparts. Consequently, if palatability is an important factor in the relationship of variety and increased intake, a diet containing many modified foods may still be associated with increased intake.

The observation by McCrory and colleagues (McCrory et al., 1999) that the increase in variety in the food supply of sweets and snacks may be associated with obesity suggests that regulating variety in these foods, while promoting variety in other foods, may be relevant for the prevention and treatment of obesity. Although it may be challenging to reduce variety across all foods consumed over time, it may be easier to focus on increasing variety in healthy foods, limiting access to the number of unhealthy foods. People may find it easier to adapt to repeating the same meats and regular-fat dairy products over time if the number of fruits and vegetables is increasing over time.

It is unclear how much sensory stimulation from food is required for sensory-specific satiety to occur. Most investigations of sensory-specific satiety instruct participants to eat a food until they are satisfied, allowing different lengths of exposure to the sensory characteristics of the food. Are the effects of repeated food presentations related to the degree of sensory exposure, or is there a critical threshold (satiation) that is required before a shift in hedonics and motivation to eat occurs? Research on repeated measurement of salivation during a meal in habituation experiments (Epstein et al., 1992) would suggest that the response is directly related to the amount of sensory experience with the food. Habituation research would also suggest that other sensory experience, such as distractions while eating (e.g., reading, watching TV), affect the amount of exposure required for sensory-specific satiety. It would be reasonable to hypothesize that the faster sensory-specific satiety begins to occur, the smaller the amount of food that will be consumed in an eating bout. Can factors that precede the initiation of a meal alter satiety? For example, the generalization of satiety across sensory modalities (E. T. Rolls & Rolls, 1997) might lead to the prediction that olfactory experience with a food prior to a meal might speed up the development of satiety after eating has begun. A greater understanding of factors

affecting the rate of sensory-specific satiety could be valuable in treating disorders that might involve satiation.

In conclusion, dietary variety seems to be an important factor in short-term and, potentially, long-term energy regulation. A better understanding of this relationship could provide valuable information regarding normal and abnormal eating behavior, potentially aiding in the development of programs designed to prevent and treat obesity.

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