Physiology & Behavior 107 (2012) 576–583

Contents lists available at SciVerse ScienceDirect

Physiology & Behavior

journal homepage: www.elsevier.com/locate/phb

Review

Dietary (sensory) variety and energy balance

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ARTICLE INFO

Article history:
Received 19 May 2012
Received in revised form 8 June 2012
Accepted 13 June 2012

Keywords:
Dietary variety
Sensory variety
Energy intake
Obesity
Energy balance
Sensory specific satiety

ABSTRACT

The prevalence of overweight and obesity in US adults is currently 68%, compared with about 47% in the early 1970s. Many dietary factors have been proposed to contribute to the US obesity epidemic, including the percentage of energy intake from fat, carbohydrate and protein; glycemic index; fruit and vegetable intake; caloric beverage intake; and fast food or other restaurant food intake. One factor that may also be important is the variety of foods in the diet having different sensory properties, that is, flavors, textures, shapes and colors. A host of studies show that when presented with a greater variety of foods within a meal, humans consume about 22% more energy compared to when only one food is available. These data are supported by laboratory animal studies on the effects of sensory variety on consumption as well as body weight and fat gain. Longer term experimental trials in humans lasting 1–2 wk had mixed results but generally showed an increase in intake of 50–60 kcal/d per additional food offered, provided at least 5 different foods per day were available. In only two studies to date has reducing dietary variety been explored as a potential method for weight loss. In those studies, which also incorporated a standard behavioral weight loss approach, there was no difference in weight loss when either snack food variety or low nutrient dense, high energy dense variety was limited. However, a broader treatment approach may be more effective, for example limiting the excess variety of foods high in energy density yet which provide little benefit to vitamin and mineral intake at each meal, and further studies are needed in this area.

Contents

1. Introduction

The prevalence of overweight and obesity continues to increase nationally and worldwide [1,2]. Globally, obesity has reached epidemic proportions, with more than one billion adults overweight, of

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0031-9384/$ – see front matter
doi:10.1016/j.physbeh.2012.06.012

whom at least 300 million of them clinically obese [3]. Overweight and obesity are linked to a host of chronic disorders, including heart disease, diabetes, arthritis-related disabilities, cancer and premature death [4]. The etiology of obesity is multifactorial involving many complex social, behavioral, environmental and genetic factors, and while the specific underlying causes of obesity and weight gain are poorly understood, the end result is positive energy balance, where more energy is consumed than expended [5]. Dietary intake is one important modifiable factor influencing energy balance, through which changes in body weight can be promoted.

Some of the dietary factors suggested to play a causal role in the development of obesity are a high intake of foods and beverages high in fat [6], free sugars [7], energy-density [8], and glycemic index [9], and a low intake of foods high in fiber [10]. One dietary factor that may also contribute, yet has been relatively understudied, is dietary variety [11,12]. While dietary variety has been traditionally considered to have positive effects on overall nutritional status, there may also be negative effects, as will be explained later in this review. In this paper we also discuss the evidence in support of a role for dietary variety in overeating and obesity development and make suggestions for future research.

2. The food environment and dietary variety

The relative importance of dietary variety in weight control is especially relevant to public health in view of the food environment in many places around the globe. In the US, for example, the per capita availability of energy per day increased by 523 kcal/d from 1970 to 2003 [13]. Concerning the availability of food variety during this time, the number of supermarkets increased dramatically in recent years promoting a greater variety of convenience and commercial foods especially in high energy density categories [14]. Likewise, using food product introductions as an example, the total number of new food products that were introduced in the US market has continued to increase over approximately the past 30 y [15]. Furthermore, as described previously [11,16], the number of new food products higher in fat and/or sugar increased disproportionately compared to those lower in fat and/or sugar, such as new fruit and vegetable products. This trend occurred from until about 2009, likely due to the fall in the US economy [17]. Interestingly, the prevalence of obesity in the US has followed a similar trend, staying relatively constant from about 2000 to the present [1].

3. Dietary variety or sensory variety vs the cafeteria diet: definition and classification

The term "dietary variety" in this review is used to describe variations across the sensory qualities of food (taste, texture, odor, and appearance), in contrast to foods additionally varying in macronutrient content and energy density. A diet consisting of foods varying in both sensory qualities and nutrient composition will readily induce hyperphagia and obesity in animal models, and is traditionally called a cafeteria diet, supermarket diet, palatable diet, or a mixed diet [18–20]. Questions arose as to whether hyperphagia could be induced by variations in sensory qualities alone, and Le Magnen [21] was the first to show that this is possible. Since then, several investigations have taken place to determine the extent to which this occurs under different conditions and these will be discussed in more detail later in this review. It should be noted that the usual diets of free-living humans do consist of foods that vary in both sensory qualities and nutrient composition; therefore, a direct translation of the findings from animal model and single-meal human studies in which nutrient composition can be controlled very well is often difficult.

The definition of "dietary variety" has been inconsistent and non-standardized across various human studies [22]. However, many studies have shown that greater dietary variety is linked with better micronutrient intakes and/or decreases in morbidity and mortality rates. These studies focused on variety among nutrient-dense food groups that can contribute to a healthy diet only [23] and omitted foods with low nutritional value [24–27]. If energy intake is not adjusted for, there is an association between dietary variety and energy intake [28], and perhaps the risk of obesity. Our group has taken a different approach and defined several types of dietary variety, such as energy dense variety and micronutrient dense variety, and these different classifications of dietary variety can be helpful in clarifying whether foods from the different types of variety in self-selected diets are likely to be associated with micronutrient status or weight status [29].

4. Effects of dietary variety on food intake and weight gain in laboratory animals

4.1. Effects on food intake

Studies in laboratory animals (Table 1) have shown overall that dietary variety increases the amount of food eaten and energy intake when the animals are fed different flavored chows. In many of these studies, nutrient composition was controlled so that the only difference between the variety condition and the control was the number of flavors or textures offered (e.g. the control group was provided one flavor while the variety group was provided three flavors). Most [21,30–35], but not all [36–38] of these studies showed that animals consumed significantly more food when fed the variety diet than when fed the control diet. In the 3 studies in which variety generally did not have a significant effect on intake, the animals were allowed ad libitum access to the foods. Note that in the Naim et al. [36] study, a variety of flavors, shapes and textures promoted intake only when the formulated diet was high in fat and sugar and not when it had normal fat and sugar content (the "nutritionally balanced" diet). However, the results could not be replicated in a second experiment. Thus, the discrepancy among study results may lie in the amount of time the animals were exposed to food, since generally the studies in which the animals were meal fed (given only limited access to the foods, e.g. a 2 h time period) show greater responses to variety compared to studies in which the animals were allowed ad libitum access (34% versus 4% between-study average increase, respectively, Table 1). Alternatively, there may be other explanations for the minimal responses to variety, including use of less preferred flavors in the varied diet compared to the control diet in the case of the Naim et al. study [36] and the use of 32% sucrose solutions rather than solid food in the study by Ackroff et al. [38], which may stimulate a high intake regardless of whether variety is offered.

The above studies were carefully controlled for nutrient composition. However, two other studies that were not completely controlled yet did not have the extremely wide variation in energy density among foods that would be provided in a cafeteria diet [39,40] are also included in Table 1, grouped by feeding scheme (meal fed or ad libitum fed). Although in these studies there was some variation in energy density of the different foods used (19.8–22.6 kJ/g in Rolls et al. [39], 11.7–13.58 kJ/g in Louis-Sylvestre et al. [40]) the increase in intake of the animals in response to variety was within the range of those in which nutrient composition was controlled, not higher as might have been expected. Rolls et al. [39] speculated that the lack of a significant effect on intake with successive compared to simultaneous offering of variety (7 versus 24%) may have been because the foods in the variety treatment were not changed often enough, as only one food was provided every 12 h within the 36 h test period. Other factors examined in these studies, including food deprivation [33,39] and pre-exposure [33] had little effect on the outcome, whereas stress [35], whether foods are offered simultaneously or successively [39], and degree of liking of the single food [41] may somewhat dampen the magnitude of the variety effect on intake.

Table 1
Animal studies of the effect of dietary variety on self-selected intake [a].

Reference	n	No. of foods or flavors in variety condition	Length of feeding, d	Magnitude of variety effect (%) [b]	Significant?
Completely controlled for nutrient composition—meal fed					
LeMagnen [21]	8	4	32	67	Y
LeMagnen [30]	10	3	39	14	Y
Morrison [31]	16	2	10	67	Y
Mugford [32]	27	3	3	47	Y
Treit et al. [33]					
Expt 1—pre-exposure [c]	24	4	4	61	Y
Expt 2—deprivation [c]	24	4	8	24	Y
Clifton et al. [34]					
Expt 1	8	4	8	24	Y
Expt 2	11	2 and 4	3 x 4d	17 (for 2), 20 (for 4)	Y
Expt 3	11	2 and 3	3 x 4d	26 (for 2), 24 (for 3)	Y
Zylan and Brown [35][c]	96	3	0	15	Y
Mean				34	
Completely controlled for nutrient composition—ad libitum fed					
Naim et al. [36]					
Expt 1—nutritionally balanced	~28	13	23	0	N
Expt 1—high fat/high sugar	~28	13	23	15	Y
Expt 2—high fat/high sugar	30	13	12	3	N
Warwick and Schiffman [37] [d]	18	3	15	0	N
Ackroff et al. [38]	20	4	8	0	N
Mean				4	
Incompletely controlled for nutrient composition—meal fed [e]					
Rolls et al. [39] Expt 1—deprivation [c]	120	3	0	19 (deprived) 33 (not deprived)	Y Y
Mean				26	
Incompletely controlled for nutrient composition—ad libitum fed [e]					
Rolls et al. [39] Expt 2—prolonged	111	3	49	24 (simultaneous) 7 (successive)	Y N
Louis-Sylvestre et al. [40]	14	13 (3 per day)	10	46	Y
Mean				26	
Weighted grand mean [f]				25	

n, number of animals.
[a] All studies listed used male rats except for Mugford et al. [32] which used cats (sex not specified), Rolls et al. [39] and Zylan and Brown [35] which each used both male and female rats, and Ackroff et al. [38] which used only female rats.
[b] Calculated as the change in the response variable in the variety condition in comparison to the change in response in the single food condition (where the single food is not chow).
[c] Unless otherwise indicated, the mean of different study conditions is presented when there was no significant effect of study condition. Studies in which means are presented: Triet et al. [33]: Expt 1, pre-exposure length; Expt 2, deprivation vs no deprivation; Zylan and Brown [35]: stress vs no stress; Rolls et al. Expt 1 [39]: simultaneous vs successive.
[d] FLAV vs CONT conditions.
[e] In Rolls et al. [39] and Louis-Sylvestre [40] studies, foods in variety condition varied slightly in energy density but within a much narrower range than the usual cafeteria diet. Rolls et al.: 19.8–22.6 kJ/g; Louis-Sylvestere et al.: 11.7–13.58 kJ/g.
[f] Weighted for the number of values from each of the 4 categories into which the studies were grouped.

Taken together, the studies in animal models show an overall calculated between-study weighted average of a 25% increase in intake in response to the offering of dietary variety compared to a single food (Fig. 1), and this effect is primarily due to varying sensory qualities of food.

4.2. Effects on body weight and fat gains

The effect of variety on body weight in laboratory animals has been examined in 4 studies (Table 2), with mixed results. The discrepant findings among these studies likely reflect many of the factors discussed in the previous section. However, in contrast to the consumption results (Table 1) which showed higher amounts consumed in experiments in which animals were meal fed (versus ad libitum fed), the weight gain outcomes show the lowest rate in the one study that used a meal feeding scheme [37]. In general, the diets that contained foods varying in sensory qualities, had a slight variation in energy density or were high in fat and sugar had the greatest impact on weight gain [36(experiment 1),39,40]. Thus, the exact contribution of sensory variety alone to weight and fat gain in

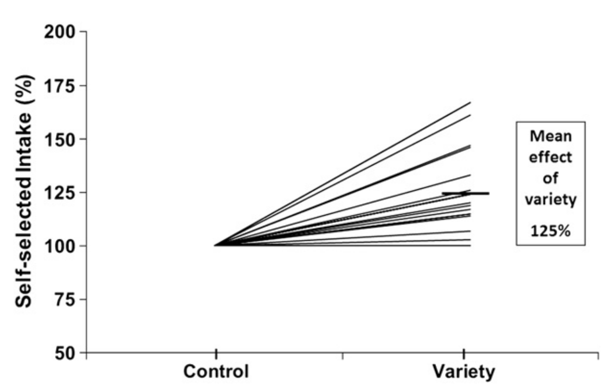

Fig. 1. Laboratory animal studies on the effects of dietary variety on self-selected intake, where the effect of variety is calculated relative to the control condition (change in the response variable in the variety condition compared to the change in response variable in the control, single food condition). Each line represents a different experiment (from Table 1) and the mean effect of variety is illustrated by the horizontal bar.

Table 2
Animal studies of the effect of dietary variety on weight and fat gain [a].

Reference	n	No. of foods in variety condition	Length of feeding, d	Response variable	Magnitude of variety effect [b]		Significant?
					%	%/d	
Rolls et al. [39][c,d,e]	111	3	49	Weight gain, body fat gain	12 (weight) 22 (fat)	0.24 (weight) 0.45 (fat)	Y
Louis-Sylvestre et al. [40] [c,e]	14	13	10	Weight gain	83	8.3	Y
Naim et al. [36][e]							
Expt 1 (nutritionally balanced)	~28	13	23	Weight gain	7	0.30	N
Expt 1 (high fat/high sugar)	~28	13	23	Weight gain	26	1.1	Y
Expt 2 (high fat/high sugar)	30	13	12	Weight gain	2	0.17	N
Warwick and Schiffman [37]	18	3	15	Weight gain	2	0.13	N

n, number of animals; M, male; F, female.
[a] All studies listed used male rats except for Rolls et al. [39] which used both male and female rats.
[b] Calculated as the change in the response variable in the variety condition in comparison to the change in response in the single food condition (where the single food is not chow).
[c] In Rolls et al. [39] and Louis-Sylvestre [40] studies, foods in variety condition varied slightly in energy density but within a much narrower range than the usual cafeteria diet.
[d] Simultaneous variety only; no effect of successive variety.
[e] Ad libitum fed.; Meal fed.

animal models remains uncertain since the Rolls et al. [39] and Louis-Sylvestre et al. [40] studies were not completely controlled for energy density and the results by Naim et al. [36] were not reproducible.

5. Dietary variety, food intake and body weight in humans

5.1. Single-meal experimental studies

Research findings on the effects of dietary variety on food consumption in humans are consistent with those observed in the animal studies. Single meal studies in humans using a within-subjects design (Table 3; Fig. 2) show a mean between-study average of 22% higher amount eaten or energy consumed with increased dietary variety [42–47]. In these studies nutrient composition was controlled and all participants ate alone. Furthermore, in most of these studies more than one sensory quality varied among the foods; however, Rolls et al. [44,45] systematically studied the impact of different sensory qualities. In one study [44] the researchers reported that 3 yogurts varying only in flavor had less impact compared to 3 yogurts varying in flavor, color and texture (3 versus 20% impact on intake; Table 3). In the other study [45], varying color alone had less impact than varying only the flavor or the shape of the foods successively (2 versus 14 and 15%, respectively). In these experiments the researchers concluded that the more dissimilar the foods are, the

Table 3
Human single-meal studies of the effects of dietary variety on self-selected intake.

Reference	Weight status or BMI, kg/m^2 (mean ± SD)	Sex	Age, y (mean ± SD or range)	n	No. foods	Differing sensory qualities	Magnitude of variety effect (%) [a]	Significant?
Within-subjects designs								
Pliner et al. [42]	NW	M	20	24			22	Y
	NW-restrained	M	20	24	3	Fl, C, T, S	31	Y
	OB	M	20	24			15	Y
Bellisle and LeMagnen [43]	Mostly NW	M,F	21–49	10	5	Fl, C	39	Y
	OW/OB	F	29–60	6			38	Y
Rolls et al. [44]								
Expt 1	Mostly NW	F	18–25	36	4	Fl, C, T	30	Y
Expt 2	NW	M,F	18–35	24	3	Fl, C, T	20	Y
Expt 3	Mostly NW	F	18–20	24	3	Fl	3	N
Rolls et al. [45]								
Expt 1	NW	M,F	16–19	24	4	C	−13 (sim); 2 (suc)	N
Expt 2	Mostly NW	M,F	18–25	24	3	S	14 (suc)	Y
Expt 3	Mostly NW	M,F	19–25	24	3	Fl	15 (suc)	Y
Spiegel and Stellar [46] [b]	UW	F	19–36	9			22 (sim); 17 (suc)	N; N
	NW	F	19–50	9	6	Fl, C, T	32 (sim); 7 suc	Y; N
	OW	F	21–44	9			43 (sim); 15 (suc)	Y; N
Hollis and Henry [47]	22.7 ± 2.6	M, F	25 ± 4	18	4	Fl, C	61	Y
	26.5 ± 3.8		72 ± 6	18	4		24	Y[c]
Mean							22	
Between-subjects designs [d]								
Beatty [48] [e]	NW, OW	M,F	"University students"	10, 12	3	Fl, C, T	3(M); 120(F)	N, Y
Berry et al. [49]	Not stated	M,F	"University students"	31, 28	3	Fl, C	Alone: 86(M), 79(F)	Y, Y
		M,F		34, 33	3		Small group: −1(M), 33(F)	N, Y
Mean							53	
Weighted grand mean [f]							29	

Abbreviations: n, number of subjects; M, male; F, female; NW, normal weight; OW, overweight; OB, obese; UW, underweight; Fl, flavor; C, color; T, texture; S, shape; sim, simultaneous presentation of variety; suc, successive presentation of variety.
[a] Calculated as the change in the response variable in comparison to the single food conditions.
[b] Foods varied slightly in energy density from 2.8 to 3.8 kcal/g.
[c] Significant age × variety interaction effect.
[d] Groups were not matched for factors affecting intake.
[e] Subjects ate in a group.
[f] Weighted for the number of values from within-subjects and between-subjects studies.

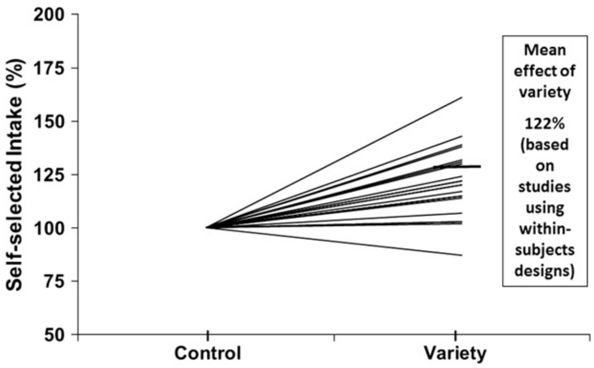

Fig. 2. Single-meal human studies on the effects of dietary variety on self-selected intake, where the effect of variety is calculated relative to the control condition (change in the response variable in the variety condition compared to the change in response variable in the control, single food condition). Each line represents a different experiment (from Table 3) and the mean effect of variety is illustrated by the horizontal bar.

greater the effect variety will have on intake. Two other studies [48,49] that used a between-subjects design showed much larger effects of variety in intake (53% on average, compared to 22% on average for the within-subjects designs, Table 3) and this could be due to several factors. First, attention was not given to matching the different groups for factors that could confound the results, such as body weight, dietary restraint or disinhibition. Second, an extremely palatable food, ice cream, was used, which may have enhanced the variety effects on intake. Finally, eating in a group may have impacted the results in some subjects more than others [48,50]. This is illustrated in the differential effect of 3 ice cream varieties in men when they ate alone (86%) versus in a group (−1%) [49]. Because of these potential problems with the within-subject design studies, they are not included in the calculation of the impact of dietary variety on intake in the single meal human studies (Fig. 2). In summary, overall results from single-meal studies in humans indicate that variety within a meal almost always resulted in increased food intake particularly when multiple sensory properties differed among foods. However, these studies were conducted over a single meal and it is important to determine if there are longer term effects of dietary variety which may lead to changes in body weight and fatness in humans.

5.2. Cross-sectional studies

One way to examine whether the effects of dietary variety extend beyond a single meal is to examine associations between dietary variety and outcomes of energy intake and/or adiposity in different populations [11,51–55]. Energy intake was positively associated with total dietary variety in adult participants in two US national surveys [54,56], as well as a small sample of frail elderly adults in a nursing home [51]. In the Roberts et al. study [54], energy intake was even better predicted by a particular type of dietary variety, energy dense variety. In another interesting study [57], 39 college-aged women with BMIs 18–25 kg/m^2 answered questions about their eating occasions on a palm computer for 7–10 d, and indicated the number of good tasting high-calorie foods that were available (not necessarily consumed) during each eating episode. They also indicated whether they ate more, less or the same amount compared to the usual amount, if they were eating during a time they usually eat or not, and if they were eating to make up for a missed meal or snack. The researchers derived a model that predicted the probability of overeating which comprised BMI, the number of palatable foods available, and their interaction, and found that those with higher BMI and who had encountered a greater number of palatable foods in their eating environment were more likely to overeat than those with lower BMI. In those with lower BMI, the number of palatable foods encountered had little impact on the risk of overeating. They also found no correlation between BMI and the number of palatable foods encountered, suggesting that the number of palatable foods encountered did not differ among those with higher versus lower BMIs. Overall, these data suggest that individuals with higher BMI have a greater affinity to palatable food variety compared to those with lower BMI.

BMI or other adiposity indicators have been used more commonly as an outcome then energy intake in studies characterizing associations with dietary variety. These studies differ widely in terms of the definition of variety, the methods used to assess dietary intake and the study populations. Despite these inconsistencies, the studies are all in general agreement that dietary variety consumed is associated with body fatness [11,51–55]; however some studies further suggest that the direction of the association differs depending on the food groups [11,54]. In particular, consumption of a greater variety of energy dense food (sweets, snacks, condiments, entrées and carbohydrates) was positively associated with percentage body fat [11] and BMI [54], and variety from vegetables was negatively associated with percentage body fat [11]. Consistent with those studies is another line of investigation in patients with anorexia nervosa who had undergone treatment showing that total dietary variety over 4 d was positively associated with treatment success up to 1-y after hospital discharge, a rating which is based on BMI [58–60].

Since many dietary components or behaviors have been suggested to play a role in the obesity epidemic, one key question concerns the relative importance of dietary variety as a predictor of adiposity in comparison to other dietary variables such as energy density or percent energy from dietary fat. Two studies conducted in different populations of Chinese adults using different methodologies showed that dietary variety was a stronger predictor of adiposity than was dietary fat [52,53] or energy density [52]. Likewise, in the study by McCrory et al. [11], a higher ratio of low-energy dense (vegetable) variety to high-energy dense variety was consumed by leaner individuals, independent of the percentage dietary fat, the latter which was not significantly associated with body fatness.

Although the above studies were cross-sectional in nature, taken together with results from experimental animal and single-meal human studies, they strongly support the suggestion that targeting dietary variety may be a crucial means of preventing and treating disorders of weight regulation. The suggested mechanism for the effects of dietary variety on intake is called "sensory specific satiety", which refers to the phenomenon that, as a food is consumed during a meal, its taste (hedonic ratings) becomes less pleasant while the taste of uneaten foods remains unchanged and appealing [61]. Theoretically then, reducing dietary variety should reduce intake by a reduction in hedonics, which should in turn lead to reductions in body weight if the reduction in intake is maintained over time. However, randomized trials are the most desirable way to examine the viability of this approach to weight loss.

5.3. Short-term intervention studies manipulating dietary variety: effects on energy intake

There are relatively few randomized trials of the effects of dietary variety on energy regulation in humans. In one intervention study, Stubbs et al. [62] examined the effects of increasing the variety of nutritionally comparable foods that differed in sensory characteristics. The subjects (6 young, lean and 6 older, overweight men) were given continuous ad libitum access over 7 d to 5, 10 or 15 food items equal in macronutrient composition while resident in a metabolic ward. They found that increasing the variety of these foods led to a significant increase in energy intake in both groups but only significantly so in the younger group. The longer term effect of altering variety of nutritionally comparable foods differing in sensory characteristics was also recently studied in our laboratory [63]. Forty-one free-living adults were assigned to one of two groups matched for age and BMI that were offered either a low variety or a high variety diet consisting of either 4 or 10 entrée/side/snack/dessert items per day, respectively. Each group was offered a single level of variety at two levels of dietary fat (20 and 42% of energy) for 13 d each in excess of energy requirements. Results showed that the high variety group consumed 329 kcal/d (16.6%) more energy than the low variety group. At the same time, the difference between low-fat and high-fat conditions was statistically significant at 77 kcal/d (3.5%); thus, the effects of variety were four times greater than the effects of dietary fat on energy intake.

An 8-d randomized trial of 39 healthy adults looked at the effects of consuming either high- or low-glycemic index/glycemic load (GI/GL) foods in either variety-(three foods per meal) or monotony-(one food per meal) conditions matched for macronutrient composition and palatability, on appetite and food intake [64]. Seventy nine foods were selected based on similar macronutrient composition and GI values. Results showed no difference in energy or macronutrient intake between the variety and monotony conditions. Possible reasons for the lack of an effect of variety in this study are that only 3 foods per meal were offered in the variety condition and this may not have been enough to stimulate greater intakes, especially given that all meals were taken in the laboratory which could alter intake relative to free-living behavior.

5.4. Can limiting variety in the diet be an effective treatment for weight loss?

Two studies to date have been conducted to determine if limiting variety could possibly be an effective treatment for obesity. In the first study, the aim was to determine the effect of limiting snack food variety on weight loss over 8 wk [65]. Thirty overweight adults participated in a standard behavioral intervention in which guidance was given to reduce energy intake to 1200–1500 kcal/d. Subjects were randomly assigned to a reduced snack food variety group in which only one flavor and type of snack food was allowed up to 4 times a week in whatever amount desired, or a control group that received standard behavioral advice concerning snack food consumption, which was to consume unlimited snack food variety types and flavors but to limit their consumption <1 serving per day. Results showed that both groups lost weight and the amount of weight loss did not differ significantly. A second study in $n=202$ adults in which the effectiveness of limiting the variety of low nutrient dense, high energy dense foods was examined in conjunction with a standard lifestyle intervention but over a longer study period also had similar results [66]. This intervention was 18 months and participants were randomly assigned to a lifestyle intervention group or a lifestyle intervention plus limited variety group. In the latter group, participants were instructed to limit the variety of low nutrient dense, high energy dense foods consumed to the same two for the entire intervention period. While the reported intake of energy from low nutrient dense, high energy dense foods was lower in the lifestyle + limited variety group, the weight loss did not differ across the two groups. Taken together, these two studies suggest that advice to limit variety in a narrow segment of the diet may not offer any advantage over lifestyle intervention alone and that a broader approach to limiting variety in the diet may be needed to have a measurable impact on body weight.

While studies which take a broader approach to limiting variety in the diet as a whole and its effects on weight loss have not been conducted, what has been done is to examine the variety in the diet that was spontaneously chosen by those who have successfully lost weight. Secondary analysis was conducted in which changes in food group variety prior to and after 6 and 18 months of obesity treatment through lifestyle intervention and the relation between changes in food group variety, dietary intake, and weight was examined in 122 obese adults [67]. Prior to treatment, variety consumed was greatest in fats, oils and sweets groups. At the end of the treatment, low-fat food groups had the greatest amount of variety. Moreover, increases in variety of low-energy dense foods and decreases in variety of high energy-dense foods were associated with weight loss. These changes were significantly associated with changes in body weight over the 18 months after controlling for demographic variables. Similar results were observed when the same research group also examined changes in dietary variety among participants in the National Weight Control Registry which consists of individuals who have lost at least 30 lb and maintained the loss for ≥ 1 y [68].

The bulk of the research from animal studies, single-meal human studies, observational studies and short-term intervention studies lasting from 1 to 8 wk suggests that reducing variety in the diet could be an effective approach for reducing body weight; however longer term studies are certainly needed in this area. Limiting variety may also be an effective means for preventing weight gain. Calculations based on the interventions conducted by McCrory et al. [63] and Stubb et al. [62] show that each additional food offered increases in intake by 50–60 kcal/d, provided at least 5 different foods per day were available. Similarly, Levitsky and Pacanowski [15] performed calculations on cross-sectional data from Smicklas-Wright [56] which indicated 42 kcal/d per additional food consumed. Therefore, reducing the variety of foods consumed by 2–3 a day could reduce or prevent energy intake of ~120–180 kcal/d, which could have a substantial impact over time on body weight. Previous work by our group [54] and that by Raynor et al. [65] indicates that the type of variety that should be targeted for reduction is energy dense variety, as this type of variety was positively associated with BMI [11,54] and spontaneous reductions in variety groups containing high fat and high sugar foods

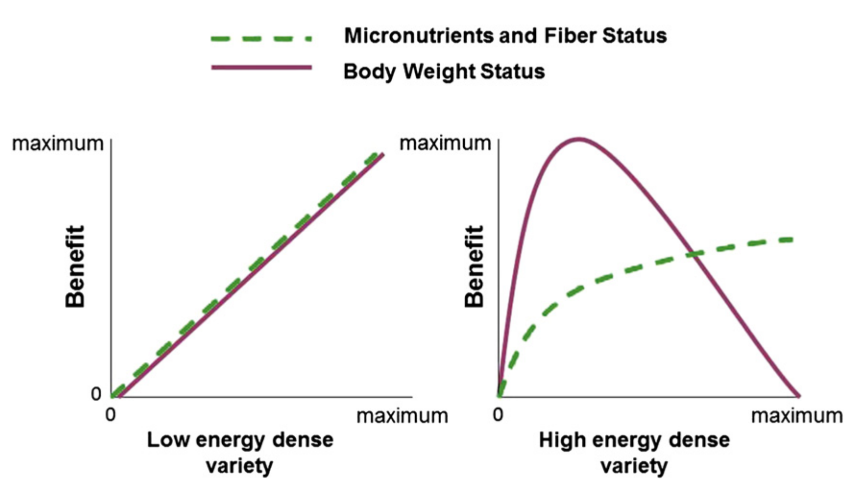

Fig. 3. Theoretical models illustrating the impact of increases in different types of dietary variety on micronutrient and fiber status and body weight status.

were associated with weight loss and its maintenance [67,68]. Furthermore, higher intakes of variety from micronutrient-dense foods, many of which are low in energy density, were positively associated with micronutrient status [54]. Theoretically then, as illustrated in Fig. 3, the more low energy dense foods there are in the diet the greater the benefit to micronutrient and body weight status, whereas high energy dense foods only benefit micronutrient status up to a point and is detrimental to body weight status when the variety consumed gets too high. There is a need to conduct long-term studies to determine what the optimal balance between energy weak and energy dense food variety in the diet should be to prevent excess weight gain and promote weight loss and successful weight loss maintenance.

6. Conclusion

Studies to date have shown that food consumption increases when there is more variety in a meal and the influence of variety on body fatness depends essentially on which food groups provide the variety. Increased energy-dense variety in the diet may lead to greater energy intake and weight gain but without benefit to micronutrient intake. In addition, benefits of variety on micronutrient intake and nutritional status are primarily seen with low energy dense, micronutrient dense variety and thus increased consumption of such variety should be emphasized. Collectively these studies suggest that the increasing variety of energy-dense foods in the U.S. and other countries may be a main contributor to the worldwide increasing prevalence of obesity. A better understanding of the relationship between dietary variety and obesity could be an important tool in the prevention and treatment of obesity, and longer-term interventions examining the role of dietary variety in the prevention and treatment of obesity are warranted.

Acknowledgments

The authors wish to thank Rachel Ebner for technical assistance with a draft of this manuscript.

References

[1] Flegal KM, Carroll MD, Kit BK, Ogden CL. Prevalence of obesity and trends in the distribution of body mass index among US adults. JAMA 1999–2010;307:491–7 [Feb 1].
[2] James PT, Leach R, Kalamara E, Shayeghi M. The worldwide obesity epidemic. Obes Res 2001;9:228S–33S.
[3] World Health Organization. WHO global strategy on diet, physical activity and health; 2004.
[4] National Heart Lung and Blood Institute. The practical guide: identification, evaluation, and treatment of overweight and obesity in adults. North American Association for the Study of Obesity. Washington, D.C: National Heart Lung and Blood Institute; 2000.
[5] McCrory MA, Suen VM, Roberts SB. Biobehavioral influences on energy intake and adult weight gain. J Nutr 2002 Dec;132:3830S–4S.
[6] Astrup A. The role of dietary fat in obesity. Semin Vasc Med 2005 Feb;5:40–7.
[7] Vermunt SH, Pasman WJ, Schaafsma G, Kardinaal AF. Effects of sugar intake on body weight: a review. Obes Rev 2003 May;4:91–9.
[8] Ledikwe JH, Blanck HM, Khan LK, Serdula MK, Seymour JD, Tohill BC, et al. Dietary energy density is associated with energy intake and weight status in US adults. Am J Clin Nutr 2006;83:1362–8.
[9] Ludwig DS. The glycemic index: physiological mechanisms relating to obesity, diabetes, and cardiovascular disease. JAMA 2002 May 8;287:2414–23.
[10] Swinburn BA, Caterson I, Seidell JC, James WP. Diet, nutrition and the prevention of excess weight gain and obesity. Public Health Nutr 2004 Feb;7:123–46.
[11] McCrory MA, Fuss PJ, McCallum JE, Yao M, Vinken AG, Hays NP, et al. Dietary variety within food groups: association with energy intake and body fatness in men and women. Am J Clin Nutr 1999 Mar;69:440–7.
[12] Raynor HA. Can limiting dietary variety assist with reducing energy intake and weight loss? Physiol Behav. Jun 6;106:356–61.
[13] Farah H, Buzby J. U.S. food consumption up 16 percent since 1970. Amber Waves; 2005 November. p. 3.
[14] Shapouri S, Rosen S. Global diet composition: factors behind the changes and implications of the new trends. Food Security Assessment 2007/GFA-19.
[15] Levitsky DA, Pacanowski CR. Free will and the obesity epidemic. PHN 2011 Sep; 19: 1–16.
[16] Gallo AE. First major drop in food product introductions in over 20 years. Food Rev 1997;20:33–5.
[17] Economic Research Service. Food marketing system in the US: new product introductions. Briefing Rooms, cited; Available from www.ers.usda.gov/briefing/FoodMarketingSystem/new_product.htm; 2010.
[18] Sclafani A, Springer D. Dietary obesity in adult rats: similarities to hypothalamic and human obesity syndromes. Physiol Behav 1976 Sep;17:461–71.
[19] Rolls BJ, Rowe EA. Dietary obesity: permanent changes in body weight [proceedings]. J Physiol 1977 Oct;272:2P.
[20] Rothwell NJ, Stock MJ. A role for insulin in the diet-induced thermogenesis of cafeteria-fed rats. Metabolism 1981 Jul;30:673–8.
[21] Le Magnen J. Hyperphagie provoquee chez le rat blanc par l'alteration du mechanisme de satiete peripherique. (Hyperphagia provoked in the white rat by the alteration of peripheral mechanisms of satiety.). C R Seances Soc Biol Fil 1956;153:32–4.
[22] Kant AK. Indexes of overall diet quality: a review. J Am Diet Assoc 1996 Aug;96: 785–91.
[23] Foote JA, Murphy SP, Wilkens LR, Basiotis PP, Carlson A. Dietary variety increases the probability of nutrient adequacy among adults. J Nutr 2004;134:1779–85.
[24] Wahlqvist ML, Sam Lo C, Meyers KA. Food variety is associated with less macrovascular disease in those with type II diabetes and their healthy controls. J Am Coll Nutr 1989;8:515–23.
[25] Kant AK, Schatzkin A, Block G, Ziegler RG, Nestle M. Food group intake patterns and associated nutrient profiles of the US population. J Am Diet Assoc 1991;91: 1532–7.
[26] Kant AK, Schatzkin A, Harris TB, Ziegler RG, Block G. Dietary diversity and subsequent mortality in the First National Health and Nutrition Examination Survey Epidemiologic Follow-up Study. Am J Clin Nutr 1993;57:434–40.
[27] Drewnowski A, Henderson SA, Driscoll A, Rolls BJ. The dietary variety score: assessing diet quality in healthy young and older adults. J Am Diet Assoc 1997;97: 266–71.
[28] Rolls BJ, Hetherington M. The role of variety in eating and body weight regulation. New York: John Wiley and Sons; 1989.
[29] McCrory MA, Roberts SB. Dietary variety. In: Markides KS, editor. Encyclopedia of health & aging. Thousand Oaks, California: SAGE Publications; 2007. p. 154–5.
[30] Le Magnen J. Effets d'une pluralite de stimuli alimentaires sur le determinisme quanitatif de l'ingestion chez le rat blanc. (Effect of a multiplicity of food stimuli on the amount eaten by the rat.). Arch Sci Physiol 1960;14:411–9.
[31] Morrison GR. Alterations in palatability of nutrients for the rat as a result of prior tasting. J Comp Physiol Psychol 1974 Jan;86:56–61.
[32] Mugford RA. External influences on the feeding of carnivores. New York: Academic Press; 1977.
[33] Triet D, Spetch ML, Deutsch JA. Variety in the flavor of food enhances eating in the rat: a controlled demonstration. Physiol Behav 1983;32:901–5.
[34] Clifton PG, Burton MJ, Sharp C. Rapid loss of stimulus-specific satiety after consumption of a second food. Appetite 1987;8:149–56.
[35] Zylan KD, Brown SD. Effect of stress and food variety on food intake in male and female rats. Physiol Behav 1996 Jan;59:165–9.
[36] Naim M, Brand JG, Kare MR, Carpenter RG. Energy intake, weight gain and fat deposition in rats fed flavored, nutritionally controlled diets in a multichoice ("cafeteria") design. J Nutr 1985 Nov;115:1447–58.
[37] Warwick ZS, Schiffman SS. Flavor–calorie relationships: effect on weight gain in rats. Physiol Behav 1991 Sep;50:465–70.
[38] Ackroff K, Bonacchi K, Magee M, Yiin YM, Graves JV, Sclafani A. Obesity by choice revisited: effects of food availability, flavor variety and nutrient composition on energy intake. Physiol Behav 2007 Oct 22;92:468–78.
[39] Rolls BJ, van Duijvenvoorde PM, Rowe EA. Variety in the diet enhances intake in a meal and contributes to the development of obesity in the rat. Physiol Behav 1983;31:21–7.
[40] Louis-Sylvestre J, Giachetti I, Le Magnen J. Sensory versus dietary factors in cafeteria-induced overweight. Physiol Behav 1984;32:901–5.
[41] Yeomans MR, Lee MD, Gray RW, French SJ. Effects of test-meal palatability on compensatory eating following disguised fat and carbohydrate preloads. Int J Obes Relat Metab Disord 2001 Aug;25:1215–24.
[42] Pliner P, Polivy J, Herman CP, Zakalusn I. Short-term intake of overweight individuals and normal weight dieters and non-dieters with and without choice among a variety of foods. Appetite 1980;1:203–13.
[43] Bellisle F, Le Magnen J. The structure of meals in humans: eating and drinking patterns in lean and obese subjects. Physiol Behav 1981;27:649–58.
[44] Rolls BJ, Rowe EA, Rolls ET, Kingston B, Megson A, Gunary R. Variety in a meal enhances food intake in man. Physiol Behav 1981;26:215–21.
[45] Rolls BJ, Rowe EA, Rolls ET. How sensory properties of foods affect human feeding behavior. Physiol Behav 1982;29:409–17.
[46] Speigel TA, Stellar E. Effects of variety on food intake of under-weight, normal-weight and overweight women. Appetite 1990;15:47–61.
[47] Hollis JH, Henry CJ. Dietary variety and its effect on food intake of elderly adults. J Hum Nutr Diet 2007 Aug;20:345–51.
[48] Beatty WW. Dietary variety stimulated appetite in females but not in males. Bull Psych Soc 1982;19:212–4.
[49] Berry SL, Beatty WW, Klesges RC. Sensory and social influences on ice cream consumption by males and females in a laboratory setting. Appetite 1985;6:41–5.
[50] Hetherington MM. Cues to overeat: psychological factors influencing overconsumption. Proc Nutr Soc 2007 Feb;66:113–23.
[51] Bernstein MA, Tucker KL, Ryan ND, O'Neill EF, Clements KM, Nelson ME, et al. Higher dietary variety is associated with better nutritional status in frail elderly people. J Am Diet Assoc 2002 Aug;102:1096–104.

[52] Yao M, McCrory MA, Ma G, Tucker KL, Gao S, Fuss P, et al. Relative influence of diet and physical activity on body composition in urban Chinese adults. Am J Clin Nutr 2003;77:1409–16.
[53] Sea MM, Woo J, Tong PC, Chow CC, Chan JC. Associations between food variety and body fatness in Hong Kong Chinese adults. J Am Coll Nutr 2004 Oct;23:404–13.
[54] Roberts SB, Hajduk CL, Howarth NC, Russell R, McCrory MA. Dietary variety predicts low body mass index and inadequate macronutrient and micronutrient intakes in community-dwelling older adults. J Gerontol A Biol Sci Med Sci 2005;60:613–21.
[55] Lyles III TE, Desmond R, Faulk LE, Henson S, Hubbert K, Heimburger DC, et al. Diet variety based on macronutrient intake and its relationship with body mass index. MedGenMed 2006;8:39.
[56] Smicklas-Wright H, Krebs-Smith S, Krebs-Smith J. Variety in foods. Washington, DC: National Academies Press; 1986.
[57] Thomas JG, Doshi S, Crosby RD, Lowe MR. Ecological momentary assessment of obesogenic eating behavior: combining person-specific and environmental predictors. Obesity (Silver Spring, Md) 2011 Aug;19:1574–9.
[58] Schebendach J, Mayer LE, Devlin MJ, Attia E, Walsh BT. Dietary energy density and diet variety as risk factors for relapse in anorexia nervosa: a replication. Int J Eat Disord. 2012 Jan;45:79–84.
[59] Schebendach JE, Mayer LE, Devlin MJ, Attia E, Contento IR, Wolf RL, Walsh BT. Food choice and diet variety in weight-restored patients with anorexia nervosa. J Amer Diet Assoc. 2011 May;111:732–6.
[60] Schebendach JE, Mayer LE, Devlin MJ, Attia E, Contento IR, Wolf RL, et al. Dietary energy density and diet variety as predictors of outcome in anorexia nervosa. Am J Clin Nutr 2008 Apr;87:810–6.
[61] Rolls BJ, Rolls ET, Rowe EA, Sweeney K. Sensory specific satiety in man. Physiol Behav 1981;27:137–42.
[62] Stubbs RJ. Effect of altering the variety of sensorially distinct foods, of the same macronutrient content, on food intake and body weight in men. Eur J Clin Nutr 2001;55:19–28.
[63] McCrory MA, Roberts SB, Gerke M, Polissar N, Oberg E, Palmer P, et al. Dietary variety increases ad-libitum energy intake more than does dietary fat: a 13-day randomized feeding trial. Obesity 2009;16(Suppl. 1):S231–2.
[64] Alfenas RC, Mattes RD. Influence of glycemic index/load on glycemic response, appetite, and food intake in healthy humans. Diabetes Care 2005 Sep;28:2123–9.
[65] Raynor HA, Niemeier HM, Wing RR. Effect of limiting snack food variety on long-term sensory-specific satiety and monotony during obesity treatment. Eat Behav 2006 Jan;7:1–14.
[66] Raynor HA, Steeves EA, Hecht J, Fava JL, Wing RR. Limiting variety in non-nutrient-dense, energy-dense foods during a lifestyle intervention: a randomized controlled trial. Amer J Clin Nutr 2012 Jun;95:1305–14.
[67] Raynor HA, Jeffery RW, Tate DF, Wing RR. Relationship between changes in food group variety, dietary intake, and weight during obesity treatment. Int J Obes 2004;28:813–20.
[68] Raynor HA, Jeffery RW, Phelan S, Hill JO, Wing RR. Amount of food group variety consumed in the diet and long-term weight loss maintenance. Obes Res 2005;13:883–90.