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Biobehavioral Influences on Energy Intake and Adult Weight Gain

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Abstract

U.S. adults are now gaining more weight and becoming obese at an earlier age than in previous years. The specific causes of adult weight gain are unknown, but may be attributed to a combination of factors leading to positive energy balance. U.S. food supply data indicate that Americans have had a gradual increase in energy intake since 1970, and that per capita energy intake was 1.42 MJ/d (340 kcal/d) higher in 1994 than that in 1984. In contrast, self-reported physical activity remained constant between 1990 and 1998. Taken together, these data indicate that the increasing trend in U.S. adult weight gain is primarily attributable to overconsumption of energy. Epidemiological and experimental studies in animals and humans provide strong evidence that biobehavioral factors such as dietary variety, liquid (vs. solid) energy, portion size, palatability (taste), snacking patterns, restaurant and other away-from-home food, and dietary restraint and disinhibition influence hunger, satiety and/or voluntary energy intake. When these eating behaviors are consistently experienced either separately or in combination over the long term, they are likely to facilitate overeating. We provide a brief overview of the evidence to date for the role of these biobehavioral factors in contributing to excess energy intake and increases in body weight over time.

Key words: obesity, weight gain, energy intake, energy balance, biobehavioral factors

Adult overweight and obesity [body mass index (BMI) ≥ 25 kg/m²] are more prevalent than ever before. In 1999 61% of U.S. adults were either overweight or obese (1), compared to 47% in 1976–1980 (2). Weight gain during adulthood has also become increasingly commonplace over the past several decades (3), and it appears that adults are now becoming obese at an earlier age than in previous years (4). The specific underlying causes of obesity and weight gain are not well understood but are likely to be multivariable rather than singular, representing some combination of factors that result in increases in energy intake, decreases in energy expenditure or both. This review focuses on potential biobehavioral influences on adult weight gain, that is, specific eating behaviors that may contribute to weight gain through overeating. Macronutrient, energy density, fiber and glycemic index influences on energy regulation have recently been reviewed elsewhere (5, 6, 7, 8, 9, 10, 11, 12, 13, 14.).

U.S. trends in overconsumption

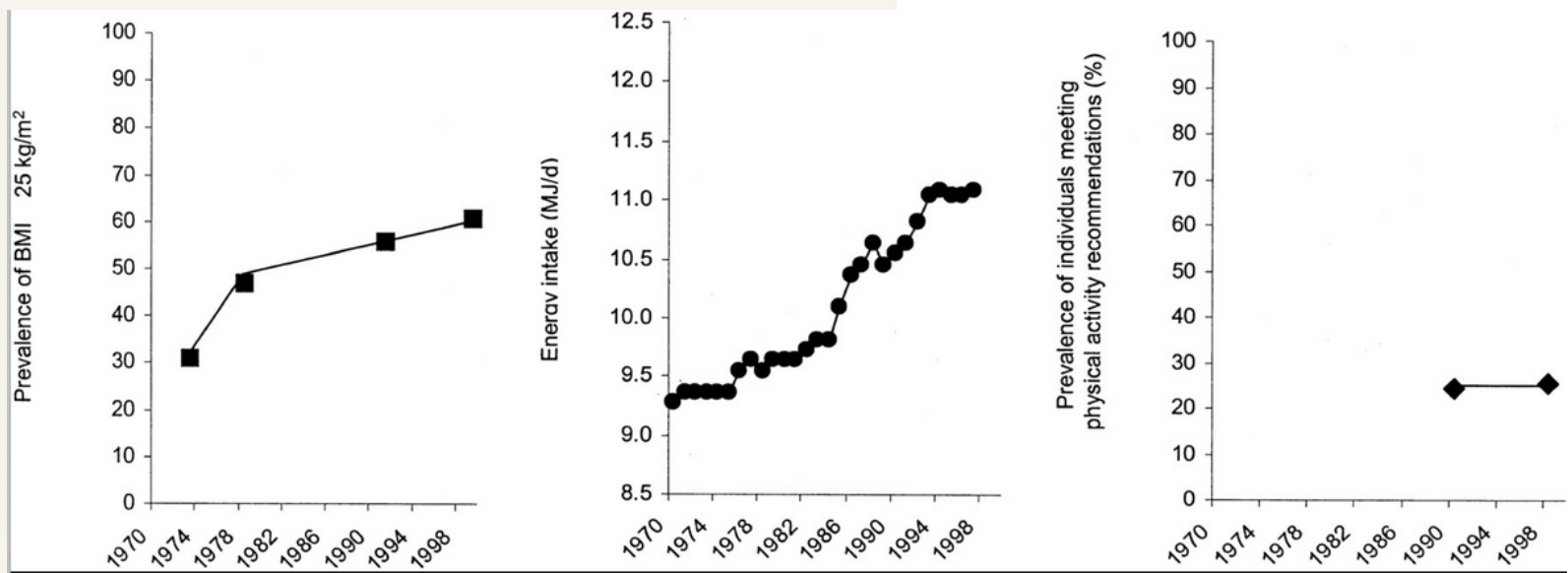
National dietary and physical activity data provide strong evidence for a demographic shift toward an overall positive energy balance in the United States that has increased over the past few decades (Fig. 1). Based on both food supply data and dietary survey data, energy intake is on the rise in all age groups from 2 to 90 y (15,16).

As shown, national food supply data adjusted for spoilage and waste indicate that Americans consumed an average of 1.42 MJ/d (340 kcal/d) more in 1994 than in 1984 and 2.09 MJ/d (500 kcal/d) more than in 1977 (17). Self-reported energy intake also increased from 1977 to 1994–1996 by 0.54–0.79 MJ/d (130–190 kcal/d) (15,16) (data not shown). The figure also shows that the prevalence of overweight and obesity over the past 30 y (1,2) has increased along with per capita energy intake. In contrast, self-reported physical activity of adults remained fairly constant between 1990 and 1998 (18). [Note that physical activity data before 1990 were either tabulated differently or the specific questions differed and therefore are not readily comparable to the 1990–1998 data. However, those data also show that self-reported physical activity remained constant between 1985 and 1991 (19).] The overall differences between these energy intake and physical activity patterns suggest that U.S. trends in adult weight gain (3,4) may largely be attributed to overconsumption of energy.

FIGURE 1. Left panel: Increase in the U.S. prevalence of overweight and obesity over the past 30 y. [Data are based on U.S. DHHS (1) and Flegal et al. (2).] Middle panel: Change over time in the United States per capita energy intake, adjusted for spoilage and waste. [Data from Putnam (17).] Right panel: Percentage of the U.S. population meeting physical activity recommendations (at least 5 d/wk moderate-intensity physical activity for ≥ 30 min, or at least 3 d/wk vigorous-intensity physical activity ≥ 20 min, or both) between 1990 and 1998. [Data from the National Center for Health Statistics (18).]

Biobehavioral influences on energy intake

Consumption of excess energy can be ascribed to a number of different factors. As summarized below, there are several biobehavioral influences on hunger, satiety and/or voluntary energy intake, including dietary variety, liquid (vs. solid) energy, portion size, palatability (taste),



snacking patterns, restaurant and other away-from-home food and dietary restraint and disinhibition. When these factors are consistently experienced either separately or in combination over the long term, they may well contribute to weight gain over time.

Dietary variety.

In short-term animal studies, dietary variety reproducibly increases energy intake, with a calculated between-study average increase of 25% ([20.](#), [21.](#), [22.](#), [23.](#), [24.](#), [25.](#), [26.](#)). Laboratory rats also increase their body weight and fatness when fed a variety of diets or foods similar in energy density over 10 d to 6 wk ([22,24](#)). Single-meal studies in adults ([27.](#), [28.](#), [29.](#), [30.](#), [31.](#), [32.](#)) are consistent with the findings in animals and also show a mean between-study 25% increase in energy intake in response to dietary variety. They are also consistent with results from a recent 7-d intervention study conducted in six young, lean and six older, overweight men ([33](#)). In a metabolic ward, subjects were given access to either 5, 10 or 15 food items equal in macronutrient composition. Energy intake and body weight increased with increasing dietary variety in the younger men, but not the older men. The reason for the different responses could possibly be attributable to the older, overweight men being cognitively restrained (consciously limiting their food intake) while in the experimental environment ([34](#)) and not eating enough to meet their energy needs in any variety condition [the older men consumed an average of $1.39 \times$ resting metabolic

(RMR) in comparison to their estimated mean energy requirements of 1.5 RMR while in the metabolic ward; the younger men, on the other hand, consumed an average of 1.77 RMR]. Alternatively, there may have been an effect of age, given that older subjects may not be as responsive to dietary variety as younger subjects ([35](#)).

The variety of foods available on the U.S. market has increased markedly over the past several decades, particularly in nutrient-poor, high energy dense categories ([36](#)). Recommendations to eat a variety of foods stem from the sound reasoning that different foods need to be consumed to increase the likelihood of obtaining all essential nutrients in adequate amounts, and are consistent with epidemiological studies showing that greater dietary variety is associated with a better micronutrient intake profile and/or reductions in morbidity and mortality ([37.](#), [38.](#), [39.](#), [40.](#), [41.](#), [42.](#), [43.](#), [44.](#)). Because of the recognized low nutrient content of foods such as cakes and cookies, the epidemiological studies have generally focused on examining variety within and among healthful foods, and did not fully account for variety from discretionary foods with low nutritional value. However, accounting for variety from several different food groups in addition to total variety may provide additional and more specific information depending on the study population. In adults aged 18–81 y who reported plausible dietary energy intakes [within $\pm 30\%$ of predicted energy requirements ([45,46](#))], consumption of a greater variety of foods high in energy density (sweets, snacks,

condiments, entrees and carbohydrates) over 6 mo was associated with higher body fatness, whereas consumption of a greater variety of foods low in energy density (vegetables) was associated with lower body fatness. In addition, a higher ratio of the variety of low energy dense to high energy dense foods was consumed by leaner individuals, independent of the percentage of dietary fat and other dietary factors (47). Although these data are cross-sectional in nature, when coupled with shorter-term experimental studies, they strongly suggest that consumption of a greater variety of foods from high energy dense sources relative to low energy dense sources may be associated with increases in body weight over the long term. They also suggest that consumption of a greater variety of low energy dense foods may be protective against the development of overweight and obesity.

Liquid (vs. solid) energy.

America's consumption of nutrient-poor, energy-dense beverages has increased over the past several years. In particular, U.S. per capita soft drink consumption in gallons increased by >60% between 1977 and 1998, whereas during the same time period milk consumption decreased by about 5% (15). Although in the 19- to 29-y-old age group consumption of nondiet soft drinks decreased slightly between 1977 and 1978 and 1994–1996, consumption of fruit drinks increased (48).

Short-term experimental studies suggest that consumption of energy-containing beverages may result in greater daily energy intakes than consumption of nonbeverage items. In a review of 42 studies examining the extent to which different foods and liquid test meals or preloads reduce energy intake in subsequent meals, Mattes (49) found that on average there is a 64% compensation for solid food (i.e., for every 100 kJ given as solid food, subsequent intake is reduced by 64 kJ), a 21% compensation for semisolid foods and a 0% compensation for energy-containing liquids. One other study that examined diet records of 323 adults aged 18–75 y showed that total energy intakes were significantly higher on days in which soda, alcohol, milk or juice was consumed compared to days in which those items were not consumed (50).

Portion size.

Portion sizes in the United States have risen dramatically. Young and Nestle (51) recently showed that the trend toward increasing package size of prepackaged food began in the late 1970s and has increased steadily ever since. Several studies show that portion size positively influences energy intake in single meals. Adults consume more energy when served larger portions initially, even when second servings are available (52., 53., 54.). For example, both normal weight and overweight men consumed significantly more lasagna when served 1000 g initially compared to when served either 426 or 225 g initially (54).

Data from Rolls and colleagues (55) suggest that this influence of portion size on energy intake may begin some time between the ages of 3 and 5 y. They reported that children aged 5 y, but not 3 y, consumed significantly increasing amounts of macaroni and cheese with increasing portion size. Whether large portion sizes at one meal are compensated for by a lower intake at a subsequent meal is not well understood. Studies suggest that this may be the case in infants (56) and younger children (57,58), but not older children (59) or adults (60, 61, 62.).

Palatability (taste).

As reviewed previously (63), numerous short-term studies in adults show that energy intake increases with meal and food palatability, independent of other dietary factors. Moreover, taste (a factor encompassed by palatability) is reported to be the single most important reason individuals choose the foods they do, even over healthfulness (64, 65, 66, 67.).

There is some evidence that palatability may influence hunger, satiety and voluntary energy intake through its effects on blood glucose concentrations. Increased palatability has been shown to augment the glycemic response to test meals (68), as well as later hunger (69,70), desire to eat (69) and energy intake at the next meal (70). Because more palatable meals result in higher glycemic responses, palatable meals may be likened to foods that have a relatively high glycemic index (GI) (71,72). High GI meals have also been shown to accelerate the return of hunger and increase subsequent energy intake (8,73).

Circulating free fatty acids (FFA) are also thought to be important in the control of food intake and are affected by GI. Plasma FFA were significantly lower 4–5 h after high GI meals compared to that after low GI meals (73,74), and both glucose and FFA concentrations independently predicted within-subject differences in subsequent meal energy intake after test meals differing in GI (73). Taken together, these studies suggest that compared to less palatable meals, more palatable meals may lead to greater subsequent hunger and energy intake through differences in metabolic and hormonal responses. It is not known, however, whether repeated consumption of palatable foods over the long term leads to weight gain.

Snacking.

Americans across all age groups are snacking more often and deriving more energy from snacks than ever before (15,16,75). According to the U.S. Department of Agriculture, the mean number of snacks consumed per day increased from 1.1 in 1977–1978 to 1.6 in 1995 for individuals > 2 y (15). In individuals aged 19–29 y, there has also been a shift in the energy density of food consumed while snacking relative to nonsnacking occasions. Zizza et al. (48) reported that in that age group, the mean energy density of snack food increased from 4.39 kJ/g (1.05 kcal/g) in 1977–1978 to 5.52 kJ/g (1.32 kcal/g) in 1994–1996, whereas the energy density of meal foods remained fairly constant during this time period [4.73 and 4.64 kJ/g (1.13 and 1.11 kcal/g), respectively].

Observational studies show that the reported total daily energy intake of adult snackers is on average 25% higher than that of nonsnackers (48,76,77). However, overweight and obese individuals tend to report consuming a lower percentage of their daily energy intake as snacks (76,78, 79, 80, 81). This apparent discrepancy may be attributed to selective underreporting of high energy dense snack-type foods (82, 83, 84, 85). In the only two experimental studies in which snacking treatments were compared to no snacking treatments, total daily energy intake was higher on snacking days vs. nonsnacking days (86,87); however, the difference was significant in only one of these studies (86).

Restaurant and other away-from-home food.

The proportion of daily energy obtained from foods prepared away from home has increased since the late 1970s across all age groups (15,16). In 1977–1978, away-from-home food accounted for 18% of energy, and increased to 34% of energy in 1995 (15). CSFII 1985 data (88) showed that “fast-food” and “restaurant” eating patterns were associated with the highest energy intakes in U.S. women aged 19–50 y compared to a “home mixed” eating pattern. U.S. national data also show that foods consumed away from home are less nutritious than foods consumed in the home, being higher in total fat and saturated fat, and lower in fiber and essential micronutrients (89).

These dietary data are in agreement with those from a study conducted in adults aged 19 to 80 y who reported plausible dietary energy intakes (90). In that study, individuals who consumed restaurant food >12.9 times/mo had a daily energy intake that was on average 31.5% higher than those who consumed restaurant food ≤4.3 times/mo. A higher frequency of consuming restaurant food was also associated with diets higher in fat and lower in fiber. Furthermore, restaurant food consumption frequency was associated with greater body fatness measured by hydrostatic weighing, independent of age, sex, physical activity, education and alcohol consumption. Restaurant food may be overeaten in part because a wide variety of palatable, energy-dense food selections are served in generally large portions. Another possible cause may be social facilitation of food intake, given that individuals tend to consume more food when eating in the presence of others (91).

Restraint and disinhibition.

Dietary restraint and disinhibition are two of three psychological constructs of eating behavior measured by the Eating Inventory (34). Dietary restraint is defined as the tendency to restrict the amount or types of foods consumed for the purpose of maintaining or losing weight (92). Dietary disinhibition can be defined as the tendency to overeat certain foods with characteristics that one finds appealing (e.g., palatability) or in response to disinhibiting stimuli (e.g., at a buffet, emotional distress or alcohol consumption) (93).

Dietary restraint scores increase and disinhibition and hunger scores decrease with weight loss ([94.](#), [95.](#), [96.](#), [97.](#), [98.](#)), whereas maintenance of weight loss is associated with higher restraint and lower disinhibition and hunger scores ([99,100](#)). A recent study of over 600 postmenopausal women aged 55–65 y suggests that dietary disinhibition and restraint may be very important determinants of adult weight gain ([101](#)). Weight change between the age intervals of 30–39 and 55–60 y, assessed by retrospective self-report, averaged +9.3 kg (validated in a subsample) and was positively predicted by current disinhibition score in multiple regression analysis. In other words, greater disinhibition was associated with greater weight gain, even after controlling for confounding factors. In addition, although dietary restraint itself did not predict weight gain, it modified the influence of disinhibition on weight gain, so that individuals who were highly restrained had less weight gain at each level of disinhibition. Although the attenuation effect of restraint was increasingly stronger with increasing disinhibition scores, on average, highly disinhibited women with high restraint gained 60% less weight than those with low restraint. More studies are needed in additional populations to confirm the study's findings. Nonetheless, the results suggest that dietary disinhibition is a critical factor promoting adult weight gain and that strategies aimed at reducing disinhibition and increasing dietary restraint may help prevent weight gain.

Summary and conclusion

In summary, national food supply and physical activity data provide evidence that U.S. trends in adult weight gain are largely attributable to repeated overconsumption of energy over time. A number of biobehavioral dietary factors appear to facilitate excess energy intake, leading to weight gain over time. Additional prospective and intervention studies are needed to confirm the findings from survey data and short-term experimental studies to establish which factors are likely to have the greatest impact on energy intake and adult weight gain over the long term. However, existing data strongly suggest that individual biobehavioral dietary habits need to be regularly self-monitored to help prevent weight gain and combat the current obesity epidemic. In addition, environmental factors such as excessive portion sizes and the lack of easy access to affordable low energy dense foods may need to be addressed at a population-wide level to effect nationwide changes.

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