

PEDIATRIC REVIEW

Modifiable risk factors in relation to changes in BMI and fatness: what have we learned from prospective studies of school-aged children?

A Must¹, EE Barish² and LG Bandini^{2,3}

¹Department of Public Health and Community Medicine, Tufts University School of Medicine, Boston, MA, USA;

²Department of Health Sciences, Boston University, Boston, MA, USA and ³Eunice Kennedy Shriver Center, University of Massachusetts Medical School, Waltham, MA, USA

Considerable interest and resources are currently being directed to primary and secondary prevention of childhood obesity among school-aged children. Intervention studies in this age group have yielded mixed results, begging the question as to whether the correct targets for intervention have been identified. To evaluate the evidence base, we reviewed prospective observational studies published in English between 1990–2007 that reported weight or fatness changes in relation to diet, physical activity, and sedentary behavior. Sugar-sweetened beverage consumption emerged as the most consistent dietary factor in association with subsequent increases in weight status or fatness. Other foods and eating patterns showed less consistent associations and when associations were present, magnitudes were generally small. This may reflect the known limitations of standard dietary methodology to assess meal patterns and dietary intake. Findings for physical activity showed more consistent inverse associations with fatness outcomes than for weight status, and as was found for dietary factors, magnitudes of association were modest. Sedentary behavior effects on weight status differ by gender in many studies, with many, but not all, showing greater positive associations among girls. The lack of consistency observed in the studies of sedentary behaviors may reflect the range of variable definitions, measurement challenges, and the changing nature of electronic media. The intrinsic interplay among eating patterns, activity and sedentary behavior adds further complexity to the interpretation of the results of these studies. More sophisticated approaches to the analysis of these complex data in future studies may maximize what is learned. Although the classic obesity risk factors seem to play a role in the development of excess weight and fatness, some more recently identified potential factors, such as sleep, warrant further investigation in prospective studies before they are ready for evaluation using more controlled study designs.

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Introduction

Considerable interest and resources are currently being devoted to primary and secondary prevention of childhood obesity among school-aged children. Epidemiologic research provides the evidence base for the design of these prevention efforts. Prospective observational studies are typically used to identify the most promising intervention elements as well as to determine the risk groups in which effects are likely to be greatest. Despite some recent modest successes,^{1–3}

school-based and community-based interventions to address childhood obesity have generally underperformed relative to expectations and their substantial cost.^{4–6} Possible reasons for modest or absent intervention effects on weight outcomes include short-time frame or low dose of intervention elements (by design or by implementation failures). An additional possibility is that intervention targets have been misidentified.

We sought to review investigations that utilized prospective study designs to identify risk factors for excess weight gain, fatness, or obesity among school-aged children. Cross-sectional studies are not considered here because of the potential for reverse causation to operate whereby elevated weight status could, for example, influence risk factor levels such as dietary pattern or activity level.

Our review is organized into two large sections, one that addresses aspects of food and beverage intake, and a second

Correspondence: Dr A Must, Department of Public Health and Family Medicine, Tufts University School of Medicine, 136 Harrison Avenue, Boston, MA 02111, USA.

E-mail: aviva.must@tufts.edu

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that addresses activity and sedentary behavior. As the environments in which children live have changed substantially over the last several decades, we consider studies from journals that were published in English between 1990–2007.

Dietary factors

The study of dietary factors in relation to weight status and obesity is complicated. Complexity arises for a number of reasons including the many aspects of diet that require consideration, such as food choices, intake of individual nutrients and calories, and eating patterns. A variety of approaches are used to measure these dietary factors, their critique is beyond the scope of this review, but their strengths and weaknesses have been comprehensively addressed.^{7–9} The methodologies for dietary assessment in children generally rely on child or proxy (usually a parent) report. Additional challenges to the study of dietary factors arise because of the varying ability of young children to accurately report what they eat, and the reality that parent reports are hampered by the fact that they often are not with their children for the majority of their daily eating occasions.

Beverages

A number of methodologic issues limit direct comparison of findings in studies of beverage consumption and weight/fatness changes. First, beverages were not defined and categorized the same way by all authors; Berkey¹⁰ combined all beverages with added sugar soda, sweetened iced tea, and non-carbonated fruit drinks into a single category, whereas Tam¹¹ grouped fruit drinks with fruit juice, for example. Second, weight status was measured in different ways: body mass index (BMI), BMI z-score, percent body fat by bioelectrical impedance BIA, skinfolds, or by dual-energy X-ray absorptiometry (DXA). Third, anthropometrics were measured directly using a standard clinical protocol in some studies and by self-report in others. Furthermore, length of follow-up, age, race, and gender compositions of the samples varied, as did the countries in which these samples were drawn. Finally, authors employed different statistical approaches and applied different criteria for statistical significance across the different studies.

Sugar-sweetened and diet beverages. We identified seven longitudinal studies conducted since the mid-1990s that considered the relationship between sugar-sweetened beverage consumption and change in adiposity; five of these found a positive association (Table 1).^{10–14} In their 19-month study of 548 US children who were approximately age 12 at baseline, Ludwig *et al.* found that BMI increased by 0.24 kg/m² ($P=0.03$) per daily sugar-sweetened beverage serving increase. This corresponded to a 60% increase in risk for becoming obese ($P=0.02$).¹² In our 10-year Massachusetts Institute of Technology (MIT) Growth and

Table 1 Studies of sugar-sweetened beverage (SSB) consumption and subsequent relative weight or fatness

Author (year)	Study design	Characteristics of study participants	Assessment of intake	Outcome measures	Exposure definitions	Main findings
Berkey (2004) ¹⁰	Baseline and two annual follow-ups	11 291 US children, 9–14 yr at baseline	FFQ	BMI	SSB = Soda, sweetened iced tea, non-carbonated fruit drinks	BMI increases 0.028 kg/m ² in boys per daily serving of sugar added beverages and 0.116 kg/m ² in boys per daily serving of diet soda; NS in girls
Blum (2005) ¹⁵	Pre-post, 2 yr apart	166 US children, 9–3 yr at baseline	24 h recall of school-day intake	BMI z score	SSB = Regular soda, HI-C, sports drinks, Kool-Aid, fruit flavored drinks, iced tea, hot chocolate	Baseline BMI z score and year 2 diet soda intake accounted for 83.1% of variance in year 2 BMI z score; NS for sugar-sweetened beverages
Johnson (2007) ¹⁶	Baseline and two biennial follow-ups	521 and 682 British children, 5 and 7 yr at baseline	3-day food records visits	DXA-estimated fat mass	SSB = fruit squashes, cordials, and fizzy drinks with added sugar; low-energy fruit drinks = reduced sugar or sugar-free fruit squashes, cordials, and diet fizzy drinks	No association between sugar sweetened beverages and fat mass; 0.65 kg gain at 9 yr per daily serving of low-energy drinks at 5 yr, and 0.31 kg gain at 9 yr per serving at 7 yr
Ludwig (2001) ¹²	Pre-post, 19 months apart	548 Boston-area children, 11.7 yr at baseline	FFQ	BMI, triceps-skinfold thickness	SSB = soda, punch, lemonade, Kool-Aid, other sweetened fruit drink, iced tea (not artificially sweetened)	0.24 kg/m ² increase per daily serving increase of SSB; incidence of obesity risk increased 60% per daily serving increase of SSB; incidence of obesity risk was reduced 60% per daily serving increase of diet soda
Phillips (2004) ¹³	Baseline and annual follow-up until 4 yr post menarche (average duration 7.2 yr)	196 non-obese US girls 8–12 yr at baseline	FFQ	BMI z score, BIA-estimated % body fat	Soda (only sugar-sweetened)	Significant positive association between soda and % body fat, no significant association with BMI z-score
Striegel-Moore (2006) ¹⁴	Baseline and 9 annual follow-ups	1210 black and 1161 white US girls, 9–10 yr at baseline	3-day food records visits	BMI	Regular soda = all non-diet carbonated beverages except water	Regular soda consumption the only significant predictor of BMI
Tam (2006) ¹¹	Pre-post, 5 yr apart	268 Australian children, 8 yr at baseline	3-day food record	BMI z score	Soft drink/cordial (sugar-sweetened) fruit juice/fruit drink	Soft drink/cordial intake at 8 yr is associated with excess weight gain 5 years later

Abbreviations: BIA, bioelectrical impedance analysis; BMI, body mass index; DXA, dual X-ray absorptiometry; FFQ, food frequency questionnaire; SSB, sugar-sweetened beverages; NS, not significant; yr, year.

Development Study of 196 adolescent girls studied annually, we also found a significant positive relationship between sugar-sweetened soda consumption and BMI z-score.¹³ In Striegel-Moore *et al.*'s analysis of ten years of prospectively collected data from the National Heart, Lung, and Blood Institute (NHLBI) Growth and Health Study of US adolescent girls, sugar-sweetened soda was the only beverage that was significantly associated with an increase in BMI.¹⁴ In their analysis of 2 years of data from the large US-based Growing up Today Study (GUTS) cohort, Berkey *et al.* also found that BMI increased (0.028 kg/m²) with each serving of sugar-sweetened beverage among boys; among girls there was no significant association.¹⁰ In 268 Australian children from the Nepean birth cohort who were 7.7 years at baseline, Tam *et al.* found that those who became overweight over the course of 5 years consumed on average 10 g more carbohydrate daily from soft drinks and cordials (sugar-sweetened syrup mixed with water to taste) than their counterparts who did not become overweight.¹¹ Although the study designs and outcome measures varied broadly among these studies, the majority point to a role for sugar-sweetened beverage consumption in increasing weight status.

Unlike sugar-sweetened beverages, diet sodas contribute no calories to a person's daily intake. Thus, one might expect diet soda to be associated with reduced weight gain. Ludwig's theoretical substitution of diet soda for sugar-sweetened soda reversed the odds ratio (OR) to an almost 60% decrease obesity risk (OR=0.44, *P*=0.03).¹² However, this relationship has not been confirmed through observational study.^{10,15,16} To the contrary, some studies have found that diet soda consumption was associated with increases in BMI. For example, among boys in the GUTS cohort, BMI increased more with each serving of diet soda than with each serving of sugar-sweetened beverage (+0.116 and +0.028 kg/m², respectively).¹⁰ In a study of British children from the Avon birth cohort, Johnson *et al.* evaluated the effect of beverage intake collected at 5 (*n*=521) and 7 (*n*=682) years on fat mass at 9 years.¹⁶ They found a positive association between what they termed 'low-energy' beverages (diet soda, reduced sugar, and sugar-free drinks) and change in body fatness over 4 years, but no association between sugar-sweetened beverages and body fat.¹⁶ Although limited to a single 24 h recall, Blum *et al.* also found a positive relationship between diet soda intake and BMI increases in a 2-year study of American children enrolled in grades 3 through 5 at baseline.¹⁵

The mechanism by which sugar-sweetened beverages may affect weight status is not clearly established; some evidence suggests that sugar-sweetened beverages may result in the accretion of excess body fat because the liquid calories are not fully compensated for by reduction in solid food intake.¹⁷⁻¹⁹ Under this scenario, some of the calories provided by soda would function as 'extra' calories. Thus, the more soda consumed, the more extra calories and the greater the relative weight gain. However, this explanation does not account for the observed BMI increases associated with diet sodas.

Several authors have proposed that rather than a direct effect of sugar-sweetened beverage consumption, beverage choice is indicative of a set of behaviors that collectively may cause weight gain. Beverage choice, in this way, would serve as a proxy for those other behaviors. In Striegel-Moore *et al.*'s study, for every 100 g of sugar-sweetened soda, non-soda calories increased by approximately 41 kcal.¹⁴ The authors suggested that soda consumption is related to other eating habits associated with beverage choice. Berkey *et al.*'s observation, that regular and diet soda have similar effects on BMI, supports such an indirect mechanism, as would occur if beverage choice was a proxy.¹⁰ In the GUTS cohort, the positive association between diet soda consumption and increased BMI did not persist after adjustment for energy intake; this implies that other aspects of dietary intake explained the relative increase in BMI.¹⁰

As diet sodas contribute no calories, the observed association with weight status begs the question, 'What concurrent food choices might be contributing to weight gain?' Some evidence implicates fast food, which is often energy dense and is frequently consumed with soda. Despite an overall increase in soft drink consumption in the population over the period during which these studies were conducted, the proportion of soft drinks consumed in the home declined; in contrast, the percentage of soft drinks consumed in restaurants and from vending machines increased.²⁰ Sugar-sweetened beverage consumption could also be indicative of non-dietary behaviors.

Coffee, tea, and fruit drinks. In the studies reviewed, no associations were seen between coffee, tea,¹⁴ or fruit drinks (variously defined)^{11,14} and subsequent weight status or fatness of children. Fruit juice, as a single food category, was shown to be associated with an increase in BMI in only one of six studies that examined it,^{10,11,14-16,21} and only after adjusting for total calories.²¹ One would expect that the association between weight gain and these beverages would be similar to that seen for sugar-sweetened soda, if incomplete compensation for calories from beverages were operative. One would expect that this would be true for fruit juice because although fructose is metabolized differently from other sugars^{22,23} fruit juice and most sugar-sweetened sodas contain similar proportions and amounts of fructose and glucose ounce for ounce.²⁴ The lack of association could be interpreted as indirect evidence for beverage choice as a proxy for other dietary and non-dietary behaviors, or it may be that these beverages are consumed at levels too low for relationships to be shown.

Milk. In contrast to other calorie-containing beverages, milk has been hypothesized to be protective against weight gain among children. This hypothesis derives from animal studies^{25,26} and epidemiological^{27,28} and clinical studies in adult humans which have shown an association between calcium intake and adiposity. The majority of the longitudinal studies we reviewed are not consistent with the

adult and animal findings. One exception, the Avon study, indicated that fat mass at age 9 decreased by approximately 0.5 kg per daily serving of milk at age 5 and 0.35 kg per daily serving of milk at age 7.¹⁶ In contrast, in the GUTS cohort, Berkey *et al.* found a positive association between milk consumption and BMI change corresponding to the calories provided by the milk itself.²⁹ Interestingly, the direct effect was only found in consumers of 1% and skim milk, and it was of borderline significance for all except boys consuming 1% milk. In our MIT Growth and Development Study that considered all dairy food consumption, we found no evidence of a longitudinal relationship between dairy food or dairy calcium intake and BMI or % body fat change.³⁰ Similarly, no association was identified in the NHLBI¹⁴ and Nepean¹¹ studies.

Food

We identified six papers that reported on the foods children eat and their effect on weight status or fat mass using prospective designs.^{13,21,31–34} Fruits and vegetables were examined in the GUTS and MIT cohorts as well as in a study by O'Loughlin^{21,33,34} which contrasted fruits and vegetables with a 'high-fat/junk food factor.' In addition, three research groups examined 'snack food' consumption.^{13,31,32}

Fruits and vegetables. Consumption of fruits and vegetables exhibited modest, yet contradictory associations with weight and/or fatness change. In the GUTS cohort,²¹ a positive relationship was found between intake of fruits and vegetables –separately and combined, and change in BMI z-score among girls, whereas a negative relationship was observed for vegetable intake (considered with or without French fries) among boys. All of these effects were small in magnitude. For girls, a positive effect of fruit and vegetable intake only emerged after controlling for total caloric intake, interpreted to suggest that for two girls eating the same number of calories, the one who ate more fruits and vegetables would have a greater increase in BMI z-score. The authors suggested that the increase in BMI might come from toppings like salad dressings and cheese, which may have been underreported. For boys, the effect observed was protective, but was not independent of total caloric intake, suggesting that this eating pattern may be associated with lower total caloric intake or other lifestyle characteristics associated with smaller BMI increases. Interestingly, the magnitude of the association (and confidence intervals) were similar for boys and girls, but in opposite directions, and, surprisingly, were similar with and without French fries included in the vegetable category.

In contrast to the findings in GUTS²¹, fruit and vegetable intake (including fruit juice but not French fries or potatoes), was found to be associated with smaller increases in percentage body fat and BMI z-score in our all-female MIT cohort.³⁴ Again, the magnitude of the effects were modest: 2 additional servings of fruits and vegetables daily were

associated with a gain of 0.5 percentage points less body fat over the course of adolescence. Finally, a 2-year study of weight gain predictors conducted among 2318 children in Montreal found no association between their 'healthy fruit and vegetable factor' and BMI change.³³ Differences in the populations studied (US versus French Canadian) variable definitions, or analytic approaches may explain the divergence of findings across these studies.

Nutrients. Only a few studies have examined the relationship between calorie, macronutrient, or fiber intake and weight gain.^{34–37} A study of 243 Australian children followed from age 2 to age 15 found positive and negative associations of fat and carbohydrate intakes, and sub-scapular skinfold thickness, although no associations were found of macronutrient intakes with BMI or triceps skinfold thickness respectively.³⁶ Berkey *et al.* found no association of fat and fiber intake with weight gain in the GUTS cohort.³⁵ Maffei *et al.*'s study of Italian children found no association between calorie or macronutrient intake and weight status once parental weight status was taken into account.³⁷ A French study found that protein intake as early as 2 years of age had a significant positive association with childhood obesity.³⁸ In our MIT cohort an additional 3 g of fiber per day was estimated to bring about the accretion of 0.5 percentage points less body fat over adolescence.³⁴ Further research to examine the prospective relationship of macronutrient intake (protein, carbohydrate, and fat, as well as fiber) and the glycemic index may add information on the relationship of dietary factors to weight gain.

Snacks. However, fruits and vegetables are considered to be 'healthful,' snack foods are often considered as their own, detrimental food group, often dubbed 'junk food' to reflect that they are generally high in both fat and calories, and low in micronutrients or micronutrient density. Different studies have adopted widely varying definitions. Studies have also investigated another aspect of snacking which considers snacks as any foods eaten outside of regular meals and/or mealtimes; these studies will be discussed below with other studies that have examined eating patterns.

Prospective studies of snack foods have consistently failed to show a link between snack food intake and excess weight or fatness gains. Field analyzed snack food consumption among GUTS participants over 2 years.³¹ We reported snack food intake in the MIT cohort over an average of 7 years of follow-up.¹³ Neither study found any association with anthropometric change after adjustment for confounding variables such as physical activity and inactivity, parental overweight, race/ethnicity, and dietary measures.^{13,31} Similarly, a high-fat/junk food factor developed by O'Loughlin *et al.* in the Montreal cohort showed no association with BMI change over one or over 2 years.³³ In the only study to show a prospective association of snack food consumption and excess body weight, the relationship was dependent upon parental weight status.³² Children with at least one

overweight parent had increases in BMI that were associated with the selection of energy dense snack foods, whereas no association between energy dense snack food intake and BMI was observed among children of non-overweight parents.³²

Eating patterns

Food away from home. Between the late 1970s and the mid-1990s, the proportion of food eaten away from home increased from 16 to 27% in the United States.³⁹ Two groups have investigated whether this population increase in food eaten away from home might have an effect on BMI in children at the individual level.^{40,41} One of the studies focused on consumption of fried food away from home among GUTS participants.⁴⁰ Consistent with the authors' hypothesis, increasing consumption was associated with an increased change in BMI. The most significant effects were found among the younger girls (9–12 years of age) and boys 13 years and over. Reductions in consumption of fried food away from home did not seem to effect subsequent weight status.⁴⁰ In the MIT study, we examined girls' consumption of food as reported at two time points at three specific types of food service establishments: quick-service, coffee-shops, and restaurants.⁴¹ The only food type that showed a significant positive relationship with change in BMI z-score was quick-service food ($P=0.0023$). Quick-service establishments included national quick-service food outlets, submarine sandwich shops, ice cream shops, and street vendors. Whereas, not specifically studied, it is likely that much of the food consumed at quick service food outlets would have been fried. Thus, these results seem to be consistent with the findings in GUTS.

Breakfast consumption. Three studies examined the role of breakfast consumption in BMI change; all of them found significant results. Affenito *et al.* found a negative association between breakfast consumption and BMI in the NHLBI Growth and Health Study after adjusting for demographic characteristics.⁴² The association did not persist after multivariate control for physical activity and energy intake, however. The study authors interpreted this observation to suggest that breakfast consumption is a marker for other healthy behaviors. A second analysis of the same cohort found that cereal consumption was longitudinally associated with lower BMI z-score and a lower risk of overweight.⁴³ A similar association was found for normal weight children in the GUTS cohort: youth who ate breakfast more often gained less weight.⁴⁴ The opposite was true for overweight children. As GUTS relies on a semi-quantitative food questionnaire, it is not possible to evaluate the types of foods eaten at breakfast. The relationship between breakfast consumption including the composition of breakfast, and weight status warrants further study.

Timing of consumption. A pair of prospective studies of the frequency and timing of a child's meals have also

been evaluated for their potential effect on weight and fitness change. In our MIT cohort, the total number of eating events (meals and snacks separated by at least 15 min), the number of evening eating events, and caloric intake in the evening were each positively related to change in BMI z-score.⁴⁵ In a 4-year study of US girls who were 5 at baseline, Francis³² looked at snacking, defined as eating between meals. Effects depended upon parental weight status: among girls from overweight families (at least one parent with a BMI ≥ 25), snacking was associated with a greater increase in BMI, whereas no association between snacking and BMI was found among girls with normal weight parents.³²

Activity, inactivity, and screen time

Weight gain is commonly attributed to energy imbalance, excess 'energy in' relative to 'energy out.' This section focuses on measures of energy expenditure, namely activity and inactivity. The activity-related modifiable risk factors that have been studied prospectively are physical activity and physical inactivity; the latter often measured as screen time.

Activity

We identified six studies in the area, all of which found significant associations between activity levels and changes in measures of adiposity, with important differences highlighted by gender and by child and parental weight status. In O'Loughlin *et al.*'s study of 15 000 Canadian children, less activity was associated with greater BMI gains. Non-participation in sports outside of school was predictive of greater BMI increases in girls in the first year of the study only. Being in the least active quintiles and not participating in sports outside of school were predictive of greater BMI increases in boys in the 2-year analysis.³³

Berkey *et al.*⁴⁶ considered changes in reported activity and activity levels by season in the GUTS cohort. The investigators also stratified their results based on BMI status. Overweight girls and boys were likely to have lower BMI with increased physical activity over 1 year. Increased activity in the winter was the only specific category that was associated with decreased BMI in overweight girls. Increased dancing, aerobics, and walking and increased activity in all seasons were associated with relative decreases in BMI among overweight boys. Among non-overweight girls, increased activity in the summer was associated with decreases in BMI. By contrast, among non-overweight boys higher levels of strength training and walking were associated with increases in BMI. Overall, decreases in BMI were observed in girls who increased dancing, aerobics, and summer activity, whereas increased BMI was seen in boys with higher levels of strength training. Although BMI has been shown to correlate well with fatness, these findings suggest that using BMI to

measure excess weight gain may produce misleading results, particularly when the exposure of interest is physical activity. As BMI does not distinguish between fat and lean mass, a person who gains muscle mass because of intense physical activity, such as weight lifting, may show gains in BMI. As of the non-specificity of BMI, additional measures such as dual energy X-ray absorptiometry (DXA), bioelectric impedance analysis (BIA), or multiple skinfold thicknesses, may be particularly illuminating in some study contexts.

Three additional studies also identified an inverse relationship between physical activity and excess adiposity. In our MIT study of initially non-overweight girls, activity was found to be inversely associated with percentage body fat gains, with some evidence that this is especially so when one or both parents were overweight.⁴⁷ Stevens *et al.*'s study of adolescent American girls found associations between 2-year increases in physical activity and reductions in percentage body fat; BMI associations were not statistically significant but were in the same direction.⁴⁸ In Moore *et al.*'s 8-year study of American children enrolled at age 4, physical activity was protective against fat mass (measured by skinfold thickness) and BMI increases. The effect was particularly strong among girls.⁴⁹ All three of these studies⁴⁷⁻⁴⁹ used measures of adiposity other than BMI. The only study that found a positive association between physical activity and a fat-based outcome measure was Horn *et al.*'s Canadian study of Mohawk children in which girls' subscapular skinfold thickness (SST) increased with physical activity; there was no association in boys.⁵⁰ Horn's exceptional finding may reflect reliance on a single upper body skinfold thickness measure.

Inactivity and screen time

Inactivity is not merely the converse of activity in that it is possible for individuals to have high levels of both. The studies we reviewed employed various inactivity definitions, but most use some measure of screen time as a proxy for inactivity or sedentary behavior.^{33,37,46,50,51}

Other studies consider television watching, or screen time as the actual variable of interest, rather than as a measure of sedentarity.^{32,47,52-55} In addition to displacing physical activity, television viewing may affect obesity through exposure to the large amounts of food advertisements on television. Several studies have found that food advertising on television is related to children's consumption of the foods advertised^{56,57} and that children's fat intake was associated with weekly hours of television.^{56,58}

Early studies of inactivity focused exclusively on television viewing time.⁵⁴ As use of VCRs and video games became more widespread, those became important variables as well. As computer usage has increased, it too is reflected in estimates of inactivity. Screen time can be broadly defined as all time spent in front of a screen or monitor. This would include all of the above activities, although some

investigators exclude time spent at the computer for homework.⁴⁶ Some of the studies reviewed here evaluated the components of screen time separately. Aggregating the constituents of screen time may be problematic because of the extent that exposure to food advertisements is the operative mechanism, inclusion of advertisement-free screen time like videos and video games would dampen associations, if present.

Studies of the effect of screen time on excess body weight have yielded somewhat mixed findings. Gender differences are commonly observed, but the patterns are inconsistent. Berkey *et al.* defined screen time as time spent watching television and videos and playing video and computer games (excluding time doing homework on the computer) in their analyses of the GUTS cohort.⁴⁶ A positive prospective association between screen time and BMI was observed only in girls, independent of weight status. Overall, the effect was of magnitude similar to physical activity, but in the opposite direction (β coefficient = 0.050 for screen time versus -0.059 for physical activity). In overweight girls, the magnitude of the effect was greater for physical activity (β = -0.165) than for screen time (β = 0.095). Screen time was not significantly related to BMI increases in boys in that study.⁴⁶ Conversely, an earlier analysis of GUTS data found that hours of screen time was positively associated with BMI increases in girls and boys, with a greater effect observed among boys.³⁵ A 2-year study of boys and girls living in Montreal also yielded results that differed by gender: video game time was associated with excess weight gain among girls, but not among boys.³³ In that study, television viewing time was not associated with BMI for either gender.³³ Horn *et al.* found that only girls had increased body fat (assessed by skinfold thickness) in association with increased screen time.⁵⁰ In Robinson *et al.*'s 2-year study of 12-year-old girls in California, no association was found between television viewing time and BMI or skinfold thickness.⁵³ It bears noting that the study designs of most of the above studies had short follow-up times of just 1 or 2 years.

Studies of television watching^{32,37,47,51,52,54,55} and screen time with longer follow-up periods yielded somewhat more consistent results, with only our study⁴⁷ failing to identify any longitudinal association with weight or fatness status. In an Italian study that analyzed data from 112 boys and girls together, television viewing (considered a proxy for inactivity) at age 8 was predictive of weight status at age 12.³⁷ Similarly, Proctor *et al.* found television viewing to be a predictor of change in BMI and skinfold thickness measures in their 7-year study of 106 children in the US.⁵¹ In a study of television viewing among 169 American girls at ages 7, 9, and 11 years, Davison *et al.* found that participants who watched more than 2 h of television per day at all three time points were more than 13 times as likely to be overweight at age 11 and were almost five times as likely to become overweight between ages 7 and 11 than their counterparts who watched 2 h or less of television per day.⁵² Finally, in a

4-year study of 183 families of 5-year-old girls at baseline, Francis found that among girls with no overweight parent, television viewing was the only significant predictor of greater BMI change.³² Conversely, among the girls in our MIT adolescent cohort, no association was found between screen time and change in body fat over an average follow up of approximately 7 years.⁴⁷ This discrepancy may reflect the replacement of screen time with other forms of inactivity (car time, hanging out, talking on phone) in older children, especially for girls.

In the MIT study, we defined inactivity as time sleeping, laying down, sitting, or standing still, and separately considered screen time (time spent watching television and videos and playing video games). An association between inactivity, but not screen time and percent body fat was observed, suggesting to the investigators that screen time may not provide an accurate assessment of inactivity. It has been shown, in fact, that resting metabolic rate is similar while reading, sitting still, or watching television⁵⁹ but it increases dramatically when playing video games.⁶⁰

Among studies that stratified by gender, more of them identified a relationship between screen time and increased excess body weight among girls than among boys.^{33,46,54} The explanation for this difference has not been established but may reflect differences in behaviors that accompany television watching between boys and girls. Crespo *et al.* found that caloric intake increases with each hour of daily television among American girls, but not among boys, suggesting that girls snack more while watching television.⁶¹ The type of television programming may also affect the associations. The Generation M Report from the Kaiser Foundation found that American boys are more likely than girls to watch sports programming and that girls are more likely to watch situation comedies ('sitcoms'). Live sporting events may run different types of advertisements than the sitcoms that girls are more likely to watch.⁶² If the advertising hypothesis is correct, then the type of advertising girls are exposed to may be an important factor in the greater association of television with weight gain observed in girls. It is also possible that television watching among boys is linked with interest in physical activity, boys who watch sports programs may also play more sports-related video games and actual sports. Perhaps boys are less apt to sit still when watching television or playing video games.

With the advent of active video games, the concept of screen time *per se* may become less useful. Future research will have to distinguish video games as active or passive. Manufacturers have produced games that require players to dance, play the guitar or drums, and replicate the actions used in athletic competition. Not surprisingly, such active gaming has been shown to result in greater energy expenditure than non-active video games.⁶³ Some of the earliest active video games have already been used in interventions (West Virginia Games for Health⁶⁴). Other

new screen time-related activities like text messaging may also become important research foci.

A final source of inactivity is sleep, which represents an inherently sedentary behavior, with a caloric requirement lower than for any other activity.^{65,66} The direction of effects of sleep duration on overweight runs counter to other sources of inactivity, however, with short sleep duration associated with excess weight. A few recent studies have shown a prospective relationship between amount of sleep early in life and weight status at endpoints ranging from 7–21 years.^{67–69} A study by Lumeng *et al.* observed this relationship over a shorter time period, finding that duration of sleep in third grade was independently associated with overweight in sixth grade.⁷⁰ These studies account for key potentially confounding factors, including age, sex, race, parental education, parental weight status, single parenthood, TV/videogame time, amount of physical activity, snacking while watching TV, and behavioral problems, among others. Interestingly, differences in risk have been shown between boys and girls, with the relationship between sleep and overweight seeming to be stronger among boys.^{71,72}

Comment

Food consumption trends and changes in time use for youth are widely believed to be potential contributors to the current obesity epidemic. Given the intense interest in childhood obesity risk factors and the research effort in this area, the number of prospective studies of school-aged youth that examined modifiable risk factors for excess weight or fatness gains is surprisingly small.

Beverage choice has received substantial attention as a potential obesity risk factor in children. In fact, the World Health Organization concluded that SSB consumption is a 'probable contributor' to the obesity epidemic.⁷³ Studies have focused specifically on sugar-sweetened beverages, diet beverages, fruit juice, and milk, alone or in combination. Much of the interest reflects the co-incidence of the dramatic increase in childhood obesity with changes in youth beverage consumption patterns. Soft drink consumption (which includes diet and unsweetened drinks) increased by 123% among school-age children between 1977/1978 and 1994/1998.²⁰ Furthermore, the number of children drinking soda on any given day increased by almost 50% in the same period. Only 4% of soft drinks reported in the later survey were diet or unsweetened (for example, seltzer water). These trends continue with more recent US data from the 1999–2002 National Health and Nutrition Examination Survey (NHANES) which estimate that 6–11-year-old children consumed more soda than in 1994–1998, and that they were drinking ten times as much regular soda as diet soda. During the same period, 12–19-year-olds consumed more than twice as much soda as the younger age group.⁷⁴ Five-fold increases in SSB consumption at the household level were documen-

ted in the UK between 1974 and 1999 based on The National Food Survey in the United Kingdom.⁷⁵

The 1999–2002 NHANES data indicate that 6–11-year olds consumed about as much milk (boys 282 g, girls 228 g) as regular soda (boys 284 g, girls 213 g), but far less fruit juice (boys 102 g, girls 96 g); sugar-sweetened fruit drinks and ades (included in the sugar-sweetened beverages category by most authors^{10,12,15,16}) were consumed at approximately the same level as fruit juice (102 g for boys, 96 g for girls).⁷⁶ However, consumption levels of certain beverages seem to change with age. For example, in the NHLBI study, girls consumed fruit juice at approximately the same level over the 9 years of the study, whereas soda consumption more than doubled to a maximum of 377 g per day in white girls and 339 g per day in black girls.¹⁴ Fruit drink consumption also increased substantially among black girls (135–204.4 g); the increase was not significant in white girls. During the same period, milk consumption decreased substantially (352–242 g per day in white girls and 244–145 g per day in black girls). Thus, compared with soda and fruit drinks, fruit juice and milk consumption levels were somewhat low by the end of the study, particularly for black girls.¹⁴

In association with weight status, sugar-sweetened beverage intake has been studied extensively, and most of the prospective studies reviewed consistently identify a relationship between sugar-sweetened beverage consumption and increased weight or gain in fatness. Although the mechanism has yet to be established, the notion that incomplete compensation for liquid calories explains this observation is challenged by the presence of similar findings in studies of diet soda. Observations are less consistent for other dietary factors, physical activity, and screen time, with some evidence that child or parent obesity status and gender may affect these relationships. Several risk factors, including sugar-sweetened beverages, breakfast, and television viewing, seem to be operating indirectly, as proxies for other dietary or activity behaviors. To the extent that these pathways are operating indirectly, interventions that target these factors may yield disappointing results.

In contrast to the consistency of findings for sugar-sweetened beverages, so-called 'healthy foods' such as fruits and vegetables were not always found to be protective against weight gain, and snack foods did not contribute significantly to weight gain. Some of the observational data suggested that where a child eats may have significant influence upon what a child eats and/or how much. The findings that eating foods away from home is associated with increased relative BMI is consistent with the observation that fast food establishments may contribute to the relationship between soda consumption and excess weight gain, either through increased portion size or because of the high-calorie content of meals eaten in these venues.

A role for inactivity in the development of excess weight or fatness has intuitive appeal given that on average, in 1998–1999, US children spent leisure-time of over 5 h per

day engaged with media, and about 3.5 of those hours were screen time.⁷⁷ The trend of increasing inactivity is observed globally, and may be particularly striking in the developing countries.⁷⁸ With limited leisure time, it has been suggested that sedentary activities like television watching may crowd out physical activity in a child's daily routine.^{52,53} Similarly, electronic media, including television, video games, and computer use, may crowd out sleep.

Historically, television hours have served as a useful proxy for non-sleep inactivity more generally: data from the Kaiser Foundation (1999) show that children who watch the most television also read more than other children, suggesting that inactive behaviors are somehow linked.⁷⁷ This association may reflect that some children have a low innate physical fitness potential, and that children who have difficulty performing physically may prefer inactive pursuits.⁵⁴ With the introduction of many new electronic media formats, including active video games, TV time as an in-activity measure may have lost its utility.

The discrepancies shown across studies which prospectively evaluated the effect of the same risk factor on weight or fatness and generally weak associations may be explained by several methodologic factors. They may reflect the well-known methodological challenges of dietary and activity assessment, with the additional obstacles presented by the study of children.^{8,9} For example, many of these studies used dietary methodologies that do not account for portion size—which may have a big effect on estimates for individual foods.⁷⁹ Child reports may be inaccurate, and parents are with their children for only part of the day. Measurement error will weaken the associations observed. Inconsistencies across studies also likely reflect the differences in the array of confounding factors included in statistical models. For example, parental weight status seems to be important for studies of classic obesity risk factors, but is often not available for consideration. Similarly, smoking status may be an important confounder, particularly for studies of weight change in adolescent girls,⁸⁰ but measures of smoking status may not be available or may be of limited validity. Additional study design differences include widely varying follow-up times and lack of longitudinally measured risk factors.

The studies reviewed also differed in the measure of weight or fatness change. Most studies used BMI or BMI z-score as the outcome variable or a dichotomous weight status variable based on BMI. A few studies also had measures of fatness based on skinfolds or estimated by bioelectric impedance analysis. Differences in effects observed are not surprising in that correlations between BMI and body fatness measures of approximately 0.7 suggest that some of the variance in BMI may be because of factors other than body fatness.⁸¹ Some of these differences in results may also reflect differences in body composition changes between boys and girls during adolescence. Studies which included both weight and fatness measures, such as our MIT Growth and

Development Study, did not generally find that risk factor associations were similar across outcomes.^{13,30,47}

As the classical obesity risk factors do seem to play a role in the weight and fatness changes in childhood and adolescents, additional factors warrant consideration. Of the numerous new risk factors hypothesized,⁸² short sleep duration as reviewed above may represent a potential new intervention target,^{83,84} and plausible mechanisms have been proposed.⁸⁵ Additional risk factors that are increasingly recognized include chronic inflammation,^{86,87} anxiety,⁸⁸ depression,⁸⁹ and behavior problems.⁹⁰

Given the pressing need for effective interventions to address childhood obesity, carefully conducted and thoughtfully analyzed prospective studies will continue to provide the basis for selecting intervention elements. New statistical approaches, such as causal regression modeling,⁹¹ promise to help guide planners to the best designs for interventions and program evaluations. Despite the many challenges, future prospective studies are needed to better define modifiable risk factors for the development of obesity among child population subgroups for subsequent testing using experimental designs.

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