Fruits and Vegetables Displace, But Do Not Decrease, Total Energy in School Lunches

Andrea B. Bontrager Yoder, MM, PhD and Dale A. Schoeller, PhD

Abstract

Background: The high overweight and obesity prevalence among US children is a well-established public health concern. Diet is known to play a causal role in obesity. Increasing fruit and vegetable (FV) consumption to recommended levels is proposed to help reduce obesity, because their bulk and low energy density are believed to reduce energy-dense food consumption (volume displacement hypothesis). This study tests this hypothesis at the lunch meal among upper-elementary students participating in a Farm to School (F2S) program.

Methods: Digital photographs of students' school lunch trays were visually analyzed to identify the food items and amounts that were present and consumed before and after the meal. Using the USDA Nutrient Database, total and FV-only energy were calculated for each tray. Analysis of total- and non-FV energy intake was performed according to (1) levels of FV energy intake, (2) FV energy density, and (3) previous years of Farm to School programming.

Results: Higher intake of FV energy displaced non-FV energy, but total energy did not decrease across FV energy intake groups. High-FV-energy-density trays showed lower non-FV energy intake than low-FV-energy-density trays (470 ± 179 vs. 534 ± 219 kcal; $p < 0.0001$). Trays from schools with more previous years of F2S programming decreased total and non-FV energy intake from school lunches (p for trend < 0.0001 , both).

Conclusions: Increased FV consumption reduces non-FV energy intake, but does not reduce total energy intake. Therefore, this study does not support the volume displacement hypothesis and suggests calorie displacement instead.

Introduction

The high prevalence of pediatric obesity in the United States and its resultant comorbidities are well documented.^{1–4} Obesity's causes are multi-faceted, but diet is generally accepted to play a major role.^{5,6} Consumption of fruits and vegetables (FV), known to be suboptimal among most of the US population,^{7–9} is often hypothesized to be a dietary factor that, if increased to recommended levels, will help ameliorate the prevalence of overweight and obesity.^{10,11} It is well demonstrated that FV contain micronutrients important for health, but the primary reason that increased FV intake is suggested within the context of the obesity epidemic is their low energy density and high fiber and water content.^{12–14} This is based on the presumption that increased intake of FV displaces energy intake from energy-dense foods.^{15–17}

Although the energy density hypothesis is well documented in the laboratory setting,^{18,19} there is less evidence that an increase in FV consumption actually displaces con-

sumption of other foods in a free-living situation such that it reduces total energy intake. In addition, most such evidence is based on self-reported dietary data and, thus, there is limitation in measuring dietary intake as a result of the inaccuracies of self-report.^{12–14,20,21} Moreover, the relationships between FV intake and adiposity or body weight are documented epidemiologically in adults, but not in children.^{12,13}

In 2009, Farm to School (F2S) programs were named by the CDC as a strategy to facilitate children's increased access to FV in the school setting.¹⁰ These programs combine nutrition and agricultural education through traditional classroom lesson formats and experiential learning alongside procurement of locally grown foods (particularly produce) for use in school lunches, with simultaneous goals of improving students' FV consumption and supporting smaller-scale, local farmers through the learning experiences and intentional purchasing.^{22,23} The experiential learning activities are selected by each community to build on the strengths and resources available within their community; typical strategies include FV taste testing,

farmer or chef classroom presentations, field trips to farms, cooking activities, or school gardens.

This study aimed to objectively measure energy intake in a free-living population to assess total-energy and FV-sourced energy intake during one meal (school lunch) to better understand the relationship of FV intake to total-meal energy intake. Assessing this relationship in a cohort involved in F2S programming facilitated assessment in a population undergoing a broad intervention aimed at increasing FV consumption. Although it was not expected that all students would attain recommended FV intake, the assumption was that more students would reach higher levels of FV energy intake than may be observed in populations not involved in some intervention to increase intake, thus providing a wider range of FV energy intakes for analysis.

Methods

Participation and Recruitment

Participants attended schools ($n=9$) taking part in a Wisconsin AmeriCorps F2S program evaluation, which evaluated changes in dietary knowledge, attitudes, and behaviors (FV intake). The Wisconsin AmeriCorps F2S program evaluation was reviewed by the University of Wisconsin–Madison Institutional Review Board (Madison, WI) and determined to be exempt. All third- through fifth-grade students participated in deidentified evaluation activities unless their parents submitted an opt-out form.

The data described here were generated from the fall 2010 iteration of the Lunch Tray Photo Observation (LTPO) Study, which used digital photography to assess third-through fifth-grade children's dietary intake at school lunch over a period of 4 days in eight schools. (The ninth school was a large district that did not permit this evaluation activity.) Briefly, AmeriCorps members were trained during a 2-hour face-to-face session. They, along with volunteers at each school (recruited and trained by AmeriCorps members), took pictures using digital cameras of students' school lunch trays before and after students ate. All AmeriCorps members were given a written document describing the LTPO protocol to use for training volunteers, which included a recommended height and angle from which to take photographs. AmeriCorps members received ongoing technical assistance from the evaluation coordinating center team by e-mail and telephone upon request; clarifications offered to a single school were promptly communicated to all schools. Tripods were not used in order to facilitate the least obstructive presence possible in the school cafeterias. Digital cameras were available upon request, but all AmeriCorps members used school-owned or personal digital cameras. Students were told that the AmeriCorps members wanted to learn about which foods they liked, and that it was important to not discard any food before having the photograph of their tray taken after they had finished eating.

Trays were numbered to enable before and after meal pairing; side-by-side tray pictures were assessed visually by one reader (trained in visually estimating food volumes) to

document the food items and their amounts (in cups) on the tray, as well as the amounts disappeared (assumed to have been consumed, in increments of 0%, 25%, 50%, 75%, and 100%); the amount consumed was calculated by difference. Foods identified visually were verified against school menus, and usual serving sizes were reported through phone or electronic communications with food service directors.

Nutrient Analysis

The USDA Nutrient Database²⁴ was used to conduct an analysis of energy values of all foods on individual school lunch trays, both as available on the tray (before eating) and as disappeared (after eating). The amounts disappeared were assumed to have been consumed. FV energy was separated from total energy for each tray¹ to enable comparison of total to FV-only energy intake. Further, the energy density of the FV on each tray was calculated, weighted according to the volume consumed, and trays were grouped according to "low" (≤ 80 kcal/cup) or "high" (> 80 kcal/cup) FV energy density based on the median energy density value of FV items appearing on trays.

Statistical Analysis

All statistical operations were performed using SAS 9.2 software (SAS Institute Inc., Cary, NC). Data were examined for distribution normality and homogeneity of variances; no transformations were required, and assumptions were met for analysis by linear regression. The data were grouped into levels of intake: no FV consumption and by quartiles of FV energy intake among the remaining trays. Between-group differences were assessed by generalized linear modeling, controlling for grade (to serve as proxy for body size differences), and also mixed modeling, additionally treating school as a random effect to account for differences in school culture: different menus; different qualities of school meals; overall acceptability of eating FV among peers; and different

¹Fruits and vegetables included all fresh and cooked FV items, including applesauce, whole or canned fruit, vegetable sides, salad bar items, and excluding juice and "extras" (olives, salsa, and marinara sauce). Fried-like potato items (hash brown triangles, visually heavily oiled potato wedges, and French fries) also were not included. The full list of FV items included is as follows: apples (fresh or baked with cinnamon), applesauce, bananas, cranberries (dried), canned mixed fruit/fruit cocktail, grapes, kiwi, melon, orange (fresh or canned mandarin oranges), pineapple (fresh slices or canned chunks), pineapple/mandarin oranges (canned mix), peaches (canned slices or chunks), pear (canned slices or chunks); vegetables—broccoli (mostly raw, some cooked), cabbage (raw, shredded), carrots (raw sticks or baby carrots, raw grated on salads, or cooked), cauliflower (raw), celery (raw), corn (cooked), cucumber (raw slices), green beans (cooked), green pepper (raw slices), kohlrabi (raw slices), lettuce/salad greens/spinach, onions (raw), peas (cooked alone or mixed with carrots), potatoes (mashed), radishes (raw), succotash/other cooked vegetable blends (cooked), tomatoes (cherry/grape or sliced raw, or as soup), and vegetable soup.

health- and nutrition-related programming. Differences in energy availability and intake were calculated between groups of average weighted FV energy density, evaluating energy outcomes (total kcal available or disappeared; FV kcal, non-FV kcal disappeared) as continuous variables (unadjusted). In addition, energy availability and intake were assessed according to previous years of F2S programming. Tukey's adjustment was applied to correct for multiple comparisons, and significance levels were set at 0.05.

Results

Subject/School Characteristics

Table 1 depicts subject and school characteristics. Subject characteristics were determined according to grade-aggregate information available from the grades specific to schools participating in the LTPO, because it was not possible to identify which individual students participated in school lunches at most schools (tray numbers did not include student IDs). Students were distributed across grades 3, 4, and 5 relatively evenly. Only 12% of trays were indistinguishable between third and fourth grades, and 23% of trays were indistinguishable between fourth and fifth grades: These cases were the result of common lunch times. Most students (88%) were Caucasian, half (49%) were eligible for free or reduced-price lunches, and most (72%) participated in the National School Lunch program. Student heights and weights were reported for six of the eight schools ($n=644$ students), from which BMI-for-age-and-sex z -scores were calculated (mean, 0.75 ± 1.09). Furthermore, 41% of students were classified as overweight or obese per CDC guidelines (BMI ≥ 85 th percentile).²⁵ For comparison, daily estimated energy requirements, using Daily Reference Intake equations specific to age and sex, were calculated, and the average for those students was 2293 ± 575 kcal. Because these schools were part of a broader evaluation of F2S programs, previous years in F2S was reported: 26% of trays came from schools new to F2S in the 2010–2011 school year, 23% were from schools with 1 previous year of programming, and 51% were from schools with 2 or 3 previous years of programming.

Brief interviews (by phone or e-mail) with food service directors or staff indicated that 72% of trays were from schools where students were allowed to select which FV items were placed on their trays, whereas 17% of trays came from schools where food service staff served students largely uniform lunch trays. The remaining 11% of trays came from two schools that used a combination of students selecting some items and portions while being served others, with menu variance from day to day. FV serving sizes were reported to be one-half cup, except for certain fruits, such as a banana or an apple, which were offered as whole items. Reported serving sizes were not used as definitive volumes; instead, they were used as a lens through which to consider food items on trays of known size in the context of all items for volume estimations. Seventy-nine percent of trays came from schools that had a salad bar, all of which included the salad bar in the cost of the school

Table 1. Student, School, and Food Service Environment Characteristics

Characteristic	N; mean $\pm$ SD; or percent (N)
Students	
Students (n^a)	845
Sex: male, % (n^a)	53.9 (455)
Trays (n^b)	2292
Grade, % (n^a)	
3	17.7 (405)
3/4 (indistinguishable)	11.6 (266)
4	30.8 (705)
4/5 (indistinguishable)	22.8 (522)
5	17.2 (394)
Ethnicity, % (n^a)	
African American	3.2 (27)
Asian American	0.7 (6)
Caucasian	88.3 (744)
Hispanic	2.7 (23)
Native American	3.6 (30)
Other	1.5 (13)
Weight status^c	
BMI z -score, mean $\pm$ SD	0.8 ± 1.1
BMI-for-age-and-sex percentile, mean $\pm$ SD	69.5 ± 28.0
Underweight, % (n)	1.7 (11)
Healthy weight, % (n)	57.8 (372)
Overweight, % (n)	15.5 (100)
Obese, % (n)	25.0 (161)
Estimated daily energy requirement, ^c kcal, mean $\pm$ SD	2293 ± 575
1/3 of EER, kcal, mean $\pm$ SD	764 ± 192
FV disappeared, cups, mean $\pm$ SD	0.40 ± 0.35
Schools	
Schools (N)	8
Students eligible (%) for FRPL, ^d mean $\pm$ SD	48.7 ± 14.6
Participation rate (%) in National School Lunch Program, ^d mean $\pm$ SD	71.8 ± 6.3
Previous years of Farm to School programming, % (n^b)	
0 (2 schools)	25.8 (591)
1 (2 schools)	23.3 (535)
≥ 2 (4 schools)	50.9 (1166)

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Table 1. Student, School, and Food Service Environment Characteristics *continued*

Characteristic	N; mean±SD; or percent (N)
School food service characteristics	
Select/serve: Students select, %	72.2
Students are served, %	16.6
Both, %	11.2
Fruit serving size	0.5 cups or a piece of fruit
Vegetable serving size	0.5 cups
Salad bar in the cafeteria, %	79.0
Students serve themselves, %	84.9
Combination of staff serves students + students serve themselves, %	15.1
Salad bar use education: ^a Minimal/in previous years, %	7.7
Current/ongoing, %	54.9
Not reported, %	37.4
Peanut butter and jelly bar in the cafeteria (self-service), %	4.5
Bread bar in the cafeteria, %	6.1
Students serve themselves/staff serves, %	49.3/50.7
Spreads: butter/peanut butter, %	50.7/49.3

^aBased on number of students from the participating grades within participating schools. Ethnicity was not available for two students.

^bNumber of lunch trays.

^cBased on a subset of students for whom height and weight information was collected ($n = 644$).

^dObtained from department of public instruction at the school level.

^eFrom among trays from schools where there was a salad bar.

N, number of observations; SD, standard deviation; EER, estimated (daily) energy requirement; FRPL, free or reduced-price lunch.

meal. Among those that had a salad bar, 85% of trays came from schools where students served themselves from the salad bar, and the rest came from schools that involved some degree of staff supervision at the salad bar. Education on use of the salad bar as a strategy for increasing FV consumption (e.g., through posters, signage, staff supervision, and assistance) was reported as “current/ongoing” for 55% of trays and as “minimal/in previous years” for 8% of trays. Additional self-serve (or staff-assisted service) food items included a peanut butter and jelly bar (4.5% of trays) and a bread bar (6% of trays) with accompanying spreads (butter and peanut butter).

Table 2 presents the results for energy content of school lunches, expressed as available and consumed (disappeared) energy for total lunch, FV only, and non-FV energy, each adjusted for grade. Total energy did not decrease across

groups of increasing FV energy intake; in fact, trays representing the most FV energy had the highest total energy consumed. Students with moderate FV consumption (approximately one-third cup FV; group 2) at lunch trended toward consuming less total energy, but not significantly less, than those with very little or slightly more FV (groups 0, 1, and 3). Non-FV energy, however, significantly decreased across FV energy intake groups (p for trend < 0.0001), from 536 kcal (trays with no FV) to 460 kcal (trays with the most FV energy intake), indicating some displacement of non-FV energy by FV energy. When school was entered as a random effect, the pattern of differences across FV energy intake groups remained in total energy intake and the differences were statistically stronger. For non-FV energy, however, the pattern was less clear and results were no longer statistically significant. An interesting observation relative to energy intake in this cohort stems from calculated estimated (daily) energy requirement (EER) among a cohort where heights and weights were provided (Table 1). Across all FV energy intake groups, total energy intake was less than one third of calculated EER, which is the target energy provision set by the National School Lunch Program. It is possible that body size is not as important in determining how much children actually eat during the school lunch, particularly because these data use visual estimations of food, and subsequently energy intake, rather than self-reported dietary intake measures.

To test for an effect of consumption of low-energy-dense FV, the trays were segregated into three groups: no FV; weighted sum of consumed FV energy densities ≤ 80 kcal/cup; and weighted sum of consumed FV energy densities > 80 kcal/cup. Table 3 presents the energy in school lunches according to these groups for total energy available and for total, FV, and non-FV energy disappeared. The total energy available was significantly different according to the weighted energy density of FV items, with no-FV and low-FV-energy-density trays showing significantly higher total energy available than high-FV-energy-density trays by 20–30 kcal (p for trend, 0.0172) and the same trays showing higher non-FV energy consumed by 60–70 kcal (p for trend, < 0.0001). There were, however, no differences in the total energy consumed. The non-FV energy consumed was much higher in no-FV and low-FV-energy-density trays than high-FV-energy-density trays (541, 534, and 470 kcal, respectively; p for trend, < 0.0001). Collectively, these data indicate that FV provided a higher proportion of energy intake for high-FV-energy-dense trays without changing total energy intake, suggesting calorie displacement rather than volume displacement.

Finally, to examine potential associations of F2S programs with total- and FV-energy intake, trays were grouped according to schools' previous years of F2S programming (Table 4). Although there were significant trends (treating the outcome as a continuous variable; $p < 0.0001$ for each) for lower total energy available on and consumed from trays with more previous years of F2S programming, adjustments for grade and school (random

Table 2. Adjusted Mean Total and FV Energy (kcal) According to Groups^a of FV kcal Consumed in School Lunches

Group	Range of FV kcal consumed	FV cups Mean±SD	N	Total kcal		FV kcal	Non-FV kcal	
				LS mean (SE) ^b	(95% CI)	LS mean (SE) ^b	LS mean (SE) ^b	(95% CI)
0	0	0.00	595	536 (13) ^d	(520, 553)	-0 (1.0) ^d	536 (13) ^d	(520, 553)
1	≥ 0 to < 15.9375	0.22 ± 0.15	410	547 (14) ^{de}	(527, 567)	8 (2.0) ^e	540 (14) ^d	(520, 559)
2	≥ 15.9375 to < 38.6125	0.36 ± 0.18	432	525 (14) ^d	(506, 544)	26 (2.0) ^f	499 (14) ^e	(480, 518)
3	≥ 38.6125 to < 77.0000	0.53 ± 0.22	406	544 (14) ^d	(524, 563)	55 (2.0) ^g	489 (14) ^{ef}	(469, 508)
4	≥ 77.0000	0.81 ± 0.35	449	583 (14) ^e	(561, 602)	123 (2.0) ^h	460 (14) ^f	(441, 478)
p for model ^b				***		***	***	
Cohen's d, group 0 vs. group 4 ^c				-0.15		-3.68	0.42	

^aGroups represent trays with no fruits and vegetables (group 0) and quartiles of the remaining trays.

^bValues are LS means (SE, 95% CIs), adjusted for grade, using generalized linear modeling, with Tukey's adjustment for multiple comparisons.

***p for model, < 0.0001.

^cCohen's d calculated from simple means and SDs (rather than LS means and SEs).

^{d,e,f,g,h}Total, non-FV, and FV energy were analyzed by mixed modeling, adjusting for grade and treating school as a random effect. Group values with different bolded superscript letters indicate significant differences ($p < 0.05$).

FV, fruits and vegetables; SD, standard deviation; LS (mean), least squares (mean); SE, standard error; CI, confidence interval.

effect) removed that significance. The same was observed for cups of, and energy from, FV. However, non-FV energy consumed was significantly lower among trays from schools with 1 or more previous years of F2S programming, by nearly 200 kcal, even after adjustments.

Discussion

This article represents estimations of energy intake at school lunches in a free-living setting, using an objective assessment based on digital photographs. Intake of energy from FV displaced non-FV energy, but total energy did not

decrease across groups of FV energy intake. Non-FV energy consumption, however, did decrease as energy consumed from FV increased. When categorized based on the weighted average energy density of the FV as consumed, trays with a high average weighted energy density of FV items showed no difference in total energy consumption than trays with low average weighted FV energy density, despite high-FV-energy-density trays having lower total energy available than low- and no-FV-energy-density trays initially. In addition, previous F2S programming was associated with reduced intake of energy from non-FV items at school lunch. Thus, these findings demonstrate that FV consumption

Table 3. Mean School Lunch Energy (kcal) Available and Disappeared According to Average Weighted FV Energy Density

Average weighted FV energy density group	N	Available	Disappeared		
		Total kcal, mean (SD)	Total kcal, mean (SD)	FV kcal mean (SD)	Non-FV kcal mean (SD)
No FV	595	739 (227)	541 (238)	0 (0)	541 (238)
Low energy dense (≤ 80 kcal/cup)	652	730 (218)	555 (218)	21 (18)	534 (219)
High energy dense (> 80 kcal/cup)	1045	711 (178)	545 (183)	75 (56)	470 (179)
p for between-group differences ^a		*	NS	***	***
Cohen's d, no FV vs. high-FV energy density ^b		0.41	-0.02	-1.68	0.35
Cohen's d, low- vs. high-FV energy density ^b		0.10	0.05	-1.19	0.33

^aCalculated using generalized linear modeling, with column name treated as a continuous variable. * $p < 0.05$; *** $p < 0.0001$.

^bCohen's d calculated from simple means and SDs.

FV, fruits and vegetables; SD, standard deviation; NS, nonsignificant.

Table 4. Mean School Lunch Energy (kcal) Available and Disappeared According to Previous Years of Farm to School Programming

Previous years of Farm to School programming	N	Available			Disappeared					
		Total kcal			Total kcal		FV kcal		Non-FV kcal	
		Mean (SD)	(95% CI)		Mean (SD)	(95% CI)	Mean (SD)	(95% CI)	Mean (SD)	(95% CI)
0	591	872 (238) ^{c#}	(585, 887)		665 (247) ^{d#}	(649, 680)	22 (31) ^{e#}	(627, 658)	643 (238) ^f	0.26 (0.30) ^h
1	535	694 (172) ^c	(678, 709)		494 (203) ^d	(477, 510)	48 (43) ^e	(430, 463)	446 (194) ^g	0.44 (0.35) ^h
≥2	1166	662 (154) ^{c#}	(651, 672)		511 (161) ^{d#}	(500, 522)	46 (59) ^{e#}	(454, 476)	465 (159) ^g	0.38 (0.37) ^h
p for trend ^a		***			***		***		***	
Cohen's d, 0 vs. ≥2 previous years ^b		1.13			0.79		-0.47		0.94	

^aAssessed by generalized linear modeling, adjusted for grade with Tukey's adjustment for multiple comparisons, with column name treated as a continuous variable. ***p < .0001.

^bCohen's d calculated from simple means and SDs.

^{c,d,e,f,g,h}Total, non-FV, and FV energy; were assessed by mixed modeling, adjusting for grade and treating school as a random effect. Values with different superscripts indicate significant differences (p < 0.05). [#]Indicates a trend of significance, 0.05 < p < 0.10.

SD, standard deviation; CI, confidence interval.

reduces the intake of non-FV food items, but does not support the hypothesis that consumption of FV, especially low-energy-dense FV, reduces energy consumption during school lunch; furthermore, F2S programming may favorably reduce consumption of non-FV energy.

The differences in mean total energy consumed ranged from 10 to 40 kcal, which, within a single meal, has the potential for biological significance if sustained over time: An increase in weight of even just 1 pound over the course of 1 year equates to just 10 kcal per day. However, the wide confidence intervals (approximately 40 kcal around each group's average) made it nearly impossible to detect statistical significance between the observed means, with the exception of the lowest and highest total energy means (groups 2 and 4, respectively). Given the nature of the estimations and the variance expected in children's eating habits, even when grouped by intake levels, this is not entirely surprising.

Our finding that higher FV energy intake displaced non-FV energy intake is novel. In the National School Lunch Program, one meal should provide approximately one third of a child's daily energy needs (550–650 kcal at the elementary level), excluding à la carte items and condiments.^{26,27} School food service directors must develop menus that simultaneously satisfy various nutrient and food group requirements (fluid milk, a meat/meat alternate, bread/grain product, and two servings of different FV, for a total of five items), with the goal of lunches providing 33% of the recommended daily allowance for calories, protein, vitamins A and C, calcium, and iron, without exceeding recommendations for total or saturated fat, in accord with the Dietary Guidelines for Americans.²⁸ Under the regulations in place in 2010 when these data were collected, elementary (third to fifth grades) school lunches were not required to offer a specific *amount* of FV, but to offer two different FV item servings as well as meet nutrient requirements; however, the offer versus serve guideline, employed by many schools, permits students to select three of five items offered to decrease food wastage.^{26,27} Because non-FV-energy intake decreases across FV energy intake groups, it appears that when students consume FV as part of their school lunch, at least some of the total energy they consume from non-FV items decreases. However, trays with the greatest observed FV energy consumption actually showed greater total energy intake at lunch. It is possible that this may have been influenced by factors for which it was not possible to adjust (at the item level) in this study, such as student BMI or economic status, which may have influenced food availability at home and students' subsequent consumption choices in school lunch.

Previous work has suggested that high-energy-density foods contribute to high caloric intake.^{29,30} In this study, high-FV-energy-density lunch trays show lower non-FV energy consumption than no-FV and low-FV-energy-density trays, but the same total energy intake. By contrast, the volumetric displacement hypothesis would expect bulky FV with lower energy density to contribute to satiety

and, consequently, lower energy intake. A recent longitudinal study in elementary-aged children also did not support increased FV consumption as displacing high-energy foods in the diet, although the measurement tool used was self-report, rather than measured.¹⁴ Again, limited menu offerings of school cafeteria meals do not offer insight into completely free-ranging eating habits, but the data are from photographs and thus are more objective than recall or food frequency questionnaire tools. Because children eat relatively little FV at school,²⁹ perhaps the displacement hypothesis is not a reasonable assumption for a school lunch setting. However, if schools are to offer meals that align with the dietary guidelines, it does not seem unreasonable to expect that adequate volumes of FV are available to satiate children in a way that lowers total caloric intake such that even the hungriest of children are satisfied in the context of the total meal. In addition, although not explored in this study, students who eat more FV volume and more FV calories may have healthier overall diets: If students consume a more-satisfying school lunch meal, they may eat fewer unhealthy snacks during the rest of the day as a result of increased satiety.

The third School Nutrition Dietary Assessment (SNDA) Study (academic year 2004–2005) reported that vegetables contributed to 9.7% (standard error [SE], 0.58) of total calories offered, and fruits contributed to 8.7% (SE 0.32) of total calories.³¹ These data show that students consumed 0%, 1.4%, 5.0%, 10.1%, and 21.1% of energy from FV (across the FV kcal intake groups). This indicates a discrepancy between what schools offer and what students consume, because 80% of trays assessed here are categorized as consuming an average of $\leq 10\%$ of energy from FV—8 percentage points lower than reported in the SNDA-III.

A limitation of this study is that these data come from program evaluation rather than from a formal research design. Various health promotion programs take place in schools, to differing degrees: All schools were part of F2S, which aims to increase students' access to, and consumption of, FV and presumably were receiving at least similar messaging, but in differing formats and doses as a result of the grassroots nature of F2S programs. It is possible, then, that the true answers to our questions are lost in the "noise" of the total school environment. Treating school as a random effect variable in our statistical analyses was one way to account for such noise. A further limitation is that our measures are of school lunches only; the photographs did not measure how FV consumption affects total daily consumption, thus missing the home environment completely. Therefore, it is possible that FV consumption at lunch influenced energy consumption in snacks or meals consumed in later meals. A third limitation is that food quantities were generally assessed in 25% increments of the food initially available on the tray; this may have obscured some small differences. It is also possible that some food item trading occurred between students, or that some items were discarded before capturing the photograph. A fourth important limitation is that the average serving sizes

reported by food service directors were not verified with actual measurements of specific menu items served on the days of data collection, nor were any food items weighed; instead, our estimations are based on visual estimations by a trained assessor. Finally, trays were not matched to individual students and their characteristics because most of the schools did not wish to provide this detail.

A major strength of this study is that the data on foods consumed were collected using an objective measure of food consumption. Other recent reports have also used digital photography to assess food intake in cafeteria or free-living settings and have found it to be a reliable estimation.^{32–34} None of those studies have evaluated the relationship of FV to total energy, although one reported 43% average waste of fruit and 31% waste of vegetables among middle school students, and 37% and 34% (respectively) among elementary students, with total energy consumed lower than recommendations by the Child Nutrition and WIC Reauthorization Act of 2004.³³ For comparison, third through fifth graders in this study, currently participating in an F2S program, wasted an average of 26% of fruit and 27% of vegetable by volume (data not shown).

Future investigations should include factors that influence what and how much of FV students consume at school lunches, characterizations of school culture, and further comparisons of FV intake in children to total energy, particularly given the recent legislation accompanying the Healthy, Hunger-Free Kids Act of 2010.³⁵ In addition, total-diet comparisons of FV energy to total energy intake would be a valuable addition to the literature; however, this is difficult given the limited ability to capture unbiased dietary intake.

Conclusions

Total energy intake was higher among students with the highest energy intake from FV in school lunches, and trays with high-FV energy density showed no difference in total energy intake than trays with low-FV energy density; rather, they showed that high-FV-energy-density trays yielded lower non-FV energy intake within the same total energy intake levels. These results do not support the volumetric displacement hypothesis, but suggest that calorie displacement occurs within the school lunch setting. Future studies should further examine factors affecting the relationship between total, FV, and non-FV energy intake.

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Address correspondence to:

Andrea B. Bontrager Yoder, MM, PhD
Research Assistant
Department of Nutritional Sciences
University of Wisconsin–Madison
1415 Linden Drive
Madison, WI 53706

E-mail: abontrageryoder@gmail.com