Controversy and Statistical Issues in the Use of Nutrient Densities in Assessing Diet Quality[1,2]

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ABSTRACT The use of nutrient densities, such as percentage of daily energy from added sugars (%E_{AS}), creates serious statistical analysis and interpretation problems. This article examines the statistical analyses used in the September 2002 National Academy of Sciences' Institute of Medicine (IOM) draft report on Dietary Reference Intakes for macronutrients. The most critical issues involve the use of a ratio, %E_{AS}, as the key analytic variable and the use of a model that does not properly control for total energy in the diet. Upon analyzing the same data from the National Health and Nutrition Examination Survey III, an alternative statistical approach using multiple regression to partition total energy into "energy from added sugars" and "energy from other sources" produced very different results than the IOM analysis. Whereas the IOM reported decreasing intakes of calcium, vitamin A, iron, and zinc with increasing %E_{AS}, we found that the association of energy from added sugars with micronutrient intake was inconsistent and small. Energy from other sources had a much stronger and consistent association with micronutrient intake. We conclude that consumption of added sugars has little or no association with diet quality. J. Nutr. 134: 2733–2737, 2004.

KEY WORDS: • *added sugars* • *dietary reference intakes* • *diet quality* • *nutrient density*

There is heated debate over whether consumption of added sugars "displaces" essential vitamins and minerals in the diet. This is sometimes referred to as the "nutrient displacement hypothesis." The debate over nutrient displacement was reflected in the deliberations of the Dietary Guidelines for Americans 2000 Advisory Committee (1) and articles published in the scientific literature (2–9).

In September 2002, the National Academy of Sciences' Institute of Medicine (IOM)[4] released the draft of its report on macronutrient consumption (10) as part of its larger project on establishing Dietary Reference Intakes. Chapters 6 and 11 and Appendix J of the report examined the role of so-called added sugars in contributing to overweight/obesity and poor diet quality. The IOM report concluded that only at levels of 25% or more of daily energy from added sugars was diet quality compromised in some population groups.

However, two key methodological choices affect the results reported in the IOM Appendix J. First, the statistical model used for the analysis is flawed because it does not properly control for total energy in the diet. Dividing by total energy does not control for it unless there are no direct effects from either the numerator or the denominator. Total energy, therefore, may be confounding the results in the IOM report. Second, the percentage of daily energy from added sugars (%E_{AS}) is a ratio-variable formed by dividing energy from added sugars by total energy. Ratio-variables in general create serious statistical analysis and interpretation problems because ratios are actually two variables. Additional problems are created by the ratio-variable %E_{AS} because energy from added sugars is a component of total energy. This creates a mathematical dependency between the numerator and the denominator.

The statistical approach used in the IOM analysis did not properly control for total energy because total energy, which includes energy from added sugars, is the denominator of the ratio-variable %E_{AS}. In addition, individuals who consume more total energy generally have greater intakes of essential micronutrients. Because total energy is strongly interrelated with energy from added sugars and micronutrient intake, the relations observed between %E_{AS} and intake of micronutrients in the IOM report may have been driven entirely by total energy consumption rather than consumption of added sugars. In other words, the relation observed between %E_{AS} and intake of micronutrients may be spurious and caused by the relations between total energy and micronutrients.

Ratio-variables combine two variables, making it impossible to determine which one is truly driving the relationship. A ratio-variable may contain hidden identities and mathematical dependencies that could generate spurious correlations and misinterpretations of the data (12,13). Most importantly, because total energy is a single variable that includes energy from added sugars and energy from macronutrients other than added sugars, it is statistically impossible in this type of analysis to determine whether the relations reported between %E_{AS} and

[1] Supported by an unrestricted gift from the Sugar Association, Inc.
[2] Supplemental Tables 1–10 are available with the online posting of this paper at www.nutrition.org.
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[4] Abbreviations used: %E_{AS}, percentage of daily energy from added sugars; AI, adequate intake; IOM, Institute of Medicine of the National Academies.

Manuscript received 18 February 2004.

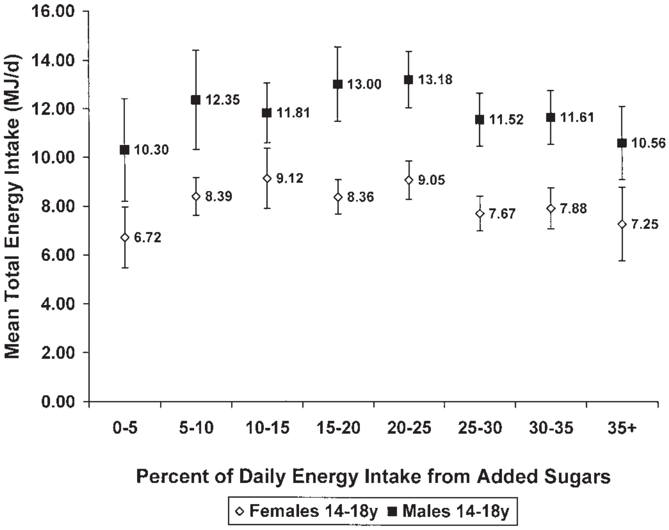

FIGURE 1 Relation between percentage of daily energy intake from added sugars (%E_{AS}) and mean total energy intake (MJ/d) for males and females 14–18 y. Data represent the mean of total energy intake (MJ/d) for each %E_{AS} category. Error bars represent the 95% CI.

intake of essential micronutrients are driven by consumption of added sugars or by the other sources of energy in the diet.

To illustrate this point, a high %E_{AS} can occur in 1 of 2 ways: *1*) consumption of added sugars is high or *2*) consumption of total energy (food intake) is low. In fact, some of the respondents in the highest %E_{AS} categories in the IOM analysis reported extremely low energy consumption. Four respondents who consumed >90% E_{AS} had mean daily energy intakes of only 0.69 MJ/d (0.20–1.20 MJ/d). The relation between total energy and %E_{AS} is not limited to a few extreme cases.

In this paper, we propose that %E_{AS} is a poor "variable of choice" in understanding the relation between added sugars consumption and diet quality. We propose that total energy intake and energy from sources other than added sugars are better predictors of micronutrient intake than %E_{AS}. Our alternative approach uses regression analyses to predict the intake of each micronutrient using gender, age, energy from added sugars (MJ/d), and energy from other macronutrients (MJ/d) as independent variables. To understand the true drivers behind micronutrient intake and diet quality, we use the energy decomposition approach because it clearly delineates the energy contribution made to total energy intake by each macronutrient.

Our intent was to replicate as closely as possible the original analysis presented in Appendix J using an alternative approach that avoided the statistical and mathematical problems created by using %E_{AS} as the key explanatory variable. This reanalysis demonstrates that a valid alternative statistical approach produces different results than those presented in Appendix J.

DATA AND METHODS

The data used in this analysis were derived from the National Health and Nutrition Examination Survey III. Collection of these data was described previously (14,15). The data set was provided to the authors by ENVIRON, the international consulting firm that conducted the statistical analysis for Appendix J at the request of the IOM.

We reanalyzed the data from Appendix J using a multiple regression approach with an energy decomposition specification. We estimated separate models for each age-gender group listed in Appendix J with each micronutrient as the dependent variable. Age, energy from added sugars (MJ/d), and energy from other sources (MJ/d) were independent variables. An α-level of 0.05 was used to determine statistical significance. The models were estimated using the *svyreg* procedure in STATA using Day 1 data and appropriate sample, strata, and pseudosampling unit weights to account for the complex design of the survey. This procedure accounts for multistage sampling using a Taylor linearization approach. We estimated separate models by adding the square of energy from other sources and the square of energy from added sugars to the specification to test for possible nonlinear relationships. There were no substantively significant differences between nonlinear and linear specifications.

RESULTS

The data showed a nonlinear relation between total energy consumption and %E_{AS} that resembled an inverted "U" (**Fig. 1**). At least 5 of the 9 age-gender categories demonstrated this pattern: children 4–8 y, males 14–18 y, males 19–50 y, females 14–18 y, and females 19–50 y. For these age-gender groups, respondents in the lowest and the highest %E_{AS} categories had relatively low total energy in their diets. Males and females over 50 y had low mean total energy consumption in the 0–5 and 30–35%E_{AS} categories, but there was an uptick in mean total energy consumption in the >35%E_{AS} category.

TABLE 1

Bivariate correlations among calcium consumption and total energy, energy from added sugars, and percentage of daily energy intake from added sugars (%E_{AS})

Population	Age	Calcium consumption correlations		
		Total energy	Energy from added sugars	%E_{AS}
	y	*95% CI*		
Children	4–8	0.61 (0.60, 0.62)	0.13 (0.11, 0.16)	−0.23 (−0.25, −0.21)
Males	9–13	0.66 (0.63, 0.68)	0.24 (0.20, 0.28)	−0.19 (−0.23, −0.15)
	14–18	0.66 (0.62, 0.71)	0.25 (0.19, 0.31)	−0.21 (−0.25, −0.16)
	19–50	0.60 (0.57, 0.62)	0.23 (0.20, 0.26)	−0.13 (−0.15, −0.11)
	+50	0.58 (0.55, 0.61)	0.24 (0.20, 0.28)	−0.09 (−0.12, −0.06)
Females	9–13	0.62 (0.60, 0.65)	0.17 (0.12, 0.21)	−0.23 (−0.27, −0.19)
	14–18	0.59 (0.56, 0.62)	0.12 (0.06, 0.18)	−0.29 (−0.33, −0.24)
	19–50	0.57 (0.54, 0.59)	0.16 (0.13, 0.19)	−0.18 (−0.21, −0.16)
	+50	0.56 (0.53, 0.59)	0.19 (0.14, 0.24)	−0.09 (−0.12, −0.06)

TABLE 2

Standardized coefficients for age, other energy, and added sugars regressed on calcium intake for all age-gender categories[1]

Population	Age	Age coeff	Other energy coeff	Added sugars coeff	R^2
	y	95% CI			
Children	4–8	0.05 (−0.02, 0.11)	0.68* (0.60, 0.76)	−0.04 (−0.11, 0.02)	0.40
Males	9–13	−0.01 (−0.09, 0.08)	0.62* (0.46, 0.79)	−0.04 (−0.11, 0.03)	0.45
	14–18	−0.03 (−0.11, 0.05)	0.63* (0.51, 0.76)	0.01 (−0.09, 0.11)	0.40
	19–50	−0.02 (−0.06, 0.01)	0.64* (0.57, 0.71)	0.06* (0.02, 0.11)	0.35
	+50	0.06* (0.00, 0.11)	0.59* (0.50, 0.69)	0.14* (0.01, 0.27)	0.35
Females	9–13	−0.01 (−0.08, 0.06)	0.73* (0.65, 0.80)	−0.10* (−0.19, −0.02)	0.45
	14–18	−0.00 (−0.08, 0.07)	0.65* (0.52, 0.78)	0.00 (−0.07, 0.07)	0.42
	19–50	−0.02 (−0.06, 0.03)	0.56* (0.51, 0.60)	0.02 (−0.02, 0.06)	0.32
	+50	0.09* (0.06, 0.13)	0.61* (0.57, 0.65)	0.05 (−0.01, 0.11)	0.37

[1] * Indicates the coefficient (coeff) is statistically significant, $P < 0.05$.

For males and females 9–13 y the patterns were choppy and did not indicate any clear relation.

The inverted "U" relation between $\%E_{AS}$ and total energy explained an important feature of the tables in the IOM Appendix J. If greater $\%E_{AS}$ were truly linked to poor diet quality, one could expect to see a consistent decline in micronutrient intake from the lowest (0–5$\%E_{AS}$) to the highest (>35$\%E_{AS}$) categories. Instead, the median micronutrient intake was substantially lower in the 0–5$\%E_{AS}$ category than in the 5–10$\%E_{AS}$ category in more than one-quarter (19 of 66) of the pairwise comparisons in Appendix J. In addition, there were no instances in which the median micronutrient intake in the 0–5$\%E_{AS}$ category was higher and substantially different than in the 5–10$\%E_{AS}$ category (10). This pattern contradicts the nutrient displacement hypothesis. We contend that this result can be explained by the low energy consumption of those in the lowest $\%E_{AS}$ category.

We examined calcium intake to further illustrate the strong relation between total energy and micronutrient intake. The bivariate correlations between total energy and calcium consumption were strong, ranging between 0.56 and 0.66 (**Table 1**). Similar bivariate correlations were observed for the other micronutrients (Supplemental Tables 1–5). In addition, the bivariate correlations between energy from added sugars and calcium consumption were also positive, but smaller, ranging between 0.12 and 0.25. In contrast, the bivariate correlations between the ratio-variable $\%E_{AS}$ and calcium consumption were negative, ranging between −0.29 and −0.09. Creating $\%E_{AS}$ reversed the direction of the relation, produced a weaker model than total energy, and obfuscated the direct relation. Total energy intake explained more of the data than did $\%E_{AS}$. In contrast to the nutrient displacement hypothesis, low total energy intake explained the low intakes of micronutrients in both the lowest and the highest $\%E_{AS}$ categories. In addition, by using total energy intake as an explanatory variable we avoided the interpretation problems of $\%E_{AS}$.

Because there were a total of 54 regression models in our reanalysis, it was not possible to provide a detailed discussion for each one, but the key findings can be summarized easily. The median coefficient for energy from other sources was 0.58 with an interquartile range from 0.43 to 0.68, whereas the median coefficient for energy from added sugars was 0.01 with an interquartile range from −0.01 to 0.05. In all models, energy from sources other than added sugars had a positive, significant relationship with consumption of the micronutrients analyzed; however, the results for energy from added sugars were inconsistent. Depending on the age group, gender,

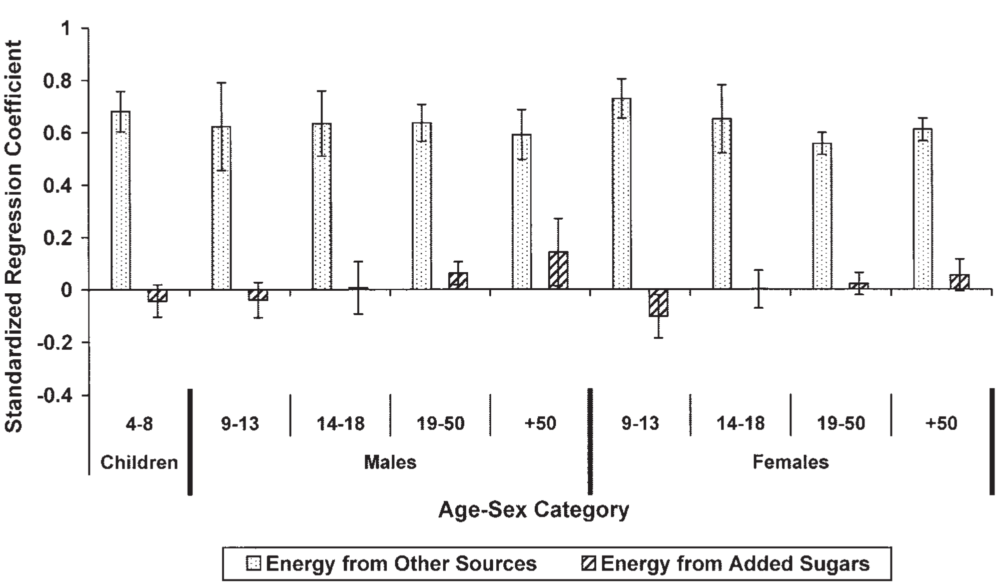

FIGURE 2 Standardized regression coefficients for consumption of energy from other sources and energy from added sugars on calcium intake while controlling for age (not shown) for all age-gender categories. The columns represent the value of the coefficient. The error bars represent the 95% CI. Variables whose error bars include zero are not significant.

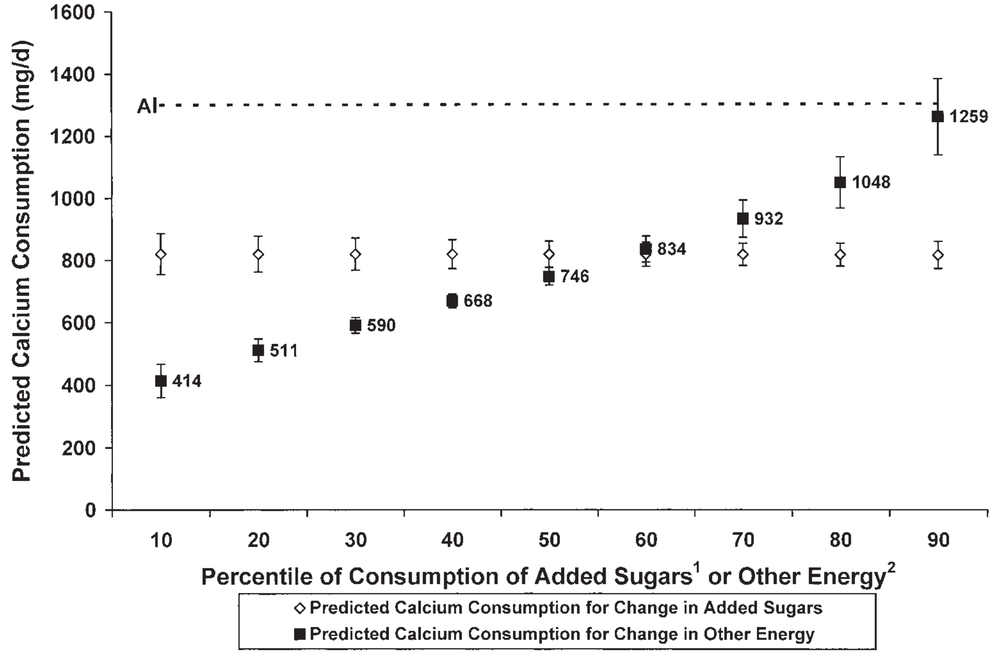

FIGURE 3 Relation between energy from added sugars (MJ/d) or energy from other sources (MJ/d) and predicted calcium consumption (mg/d) in females 14–18 y. The data represent the predicted value for calcium consumption based on the regression model at the 10th through the 90th percentile of energy from added sugars or energy from other sources with all other variables in the model set at their mean values. The error bars represent the 95% confidence interval of the prediction. Adequate intake for calcium for females 14–18 y is 1300 mg/d (16). [1]Energy from added sugars ranged from 0.48 (10th percentile) to 2.86 MJ/d (90th percentile). [2]Energy from other sources ranged from 3.05 (10th percentile) to 10.90 MJ/d (90th percentile).

and micronutrient, the relation with energy from added sugars was sometimes negative and sometimes positive, and sometimes there was no significant relation. The magnitude of the relation for energy from added sugars was always much smaller than the magnitude of the relation for energy from other sources. Generally, the relation for energy from added sugars (whether positive or negative) was one-tenth to one-fifth the size of the relation for energy from other sources.

We focused our discussion on the results from the calcium intake models (**Table 2**, **Fig. 2**), but the results for the other micronutrients were similar (Supplemental Tables 6–10). The standardized coefficient for consumption of energy from added sugars on calcium intake was positive and significant for males 19–50 y and for males over 50 y, whereas it was negative and significant for females 9–13 y. In contrast, the coefficient for energy from other sources on calcium intake was positive, significant, and relatively large for all age-gender categories.

The results of the regression analyses also showed how changes in the relative consumption of added sugars and other energy sources were associated with micronutrient intake. We examined the predicted values from an nonstandardized regression model using the same variables for females and males 14–18 y (**Figs. 3** and **4**). This age group was selected because it has the lowest percentage of individuals meeting the adequate intake (AI) for calcium. Predicted values for calcium intake by females 14–18 y were calculated as intake of energy from added sugars and energy from other sources varied from the 10th to the 90th percentiles. All other variables in the

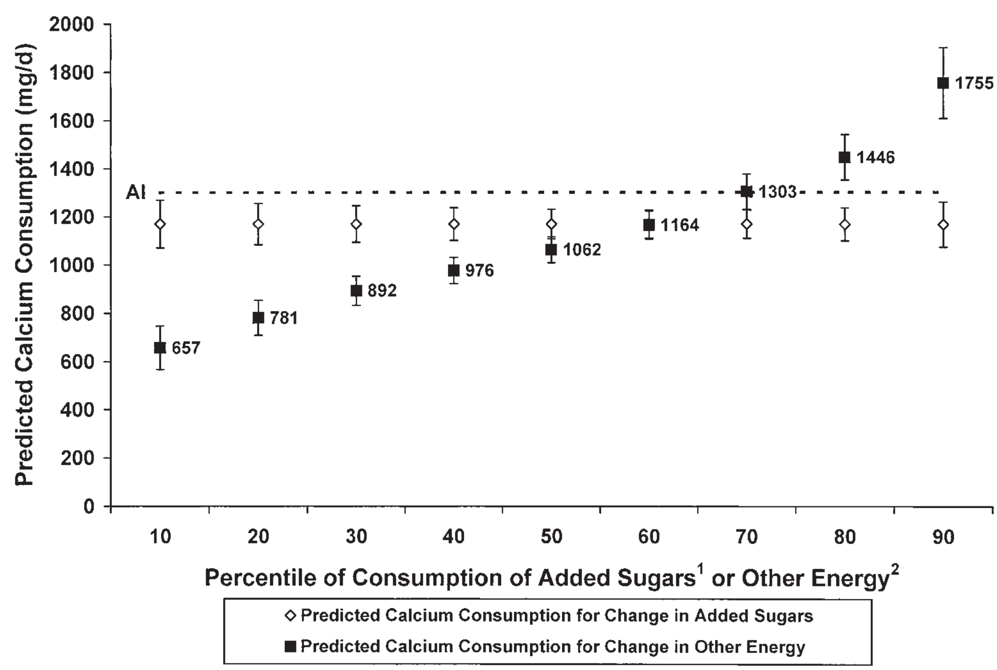

FIGURE 4 Relation between energy from added sugars (MJ/d) or energy from other sources (MJ/d) and predicted calcium consumption (mg/d) in males 14–18 y. The data represent the predicted value for calcium consumption based on the regression model at the 10th through the 90th percentile of energy from added sugars or energy from other sources with all other variables in the model set at their mean values. The error bars represent the 95% confidence interval of the prediction. Adequate intake for calcium for males 14–18 y is 1300 mg/d (16). [1]Energy from added sugars ranged from 0.61 (10th percentile) to 4.15 MJ/d (90th percentile). [2]Energy from other sources ranged from 4.58 (10th percentile) to 15.35 MJ/d (90th percentile).

regression model were held constant at their means. The 3 lines on each chart represent: *1*) the AI for calcium (1300 mg/d) (16), *2*) predicted intake of calcium (mg/d) as energy from added sugars moves from the 10th percentile (0.48 MJ/d) to the 90th percentile (2.86 MJ/d), and *3*) predicted intake of calcium (mg/d) as energy from other sources increases from the 10th percentile (3.05 MJ/d) to the 90th percentile (10.90 MJ/d). The range from the lowest point to the highest point on each line shows the overall change that could theoretically be achieved by moving someone from the 10th to the 90th percentile or vice versa. For females 14–18 y, moving from the 10th to the 90th percentile of energy from other sources increased calcium intake by 845 mg/d from a predicted value of 414 to 1259 mg/d, or only 41 mg/d less than the AI for calcium. The same shift for energy from added sugars decreased calcium consumption by 6 mg/d (from 821 to 815 mg/d), a difference that is biologically unimportant. Even at the 90th percentile of energy from other sources and at the mean intake of energy from added sugars, the predicted value for calcium intake was below the AI for females 14–18 y. By comparison, the IOM report showed that the median calcium intake for females 14–18 y was 689 mg/d in the 0–5%E_{AS} category and 434 mg/d in the >35%E_{AS} category, a difference of 255 mg/d. The 10–15%E_{AS} category had the highest median intake of calcium at 938 mg/d.

The pattern for males was similar to that for females, but the predicted values of calcium consumption were higher. Predicted calcium intake ranged from 1170 mg/d at the 10th percentile of energy from added sugars to 1166 mg/d at the 90th percentile. Moving from the 10th to the 90th percentile of energy from other sources increased predicted calcium consumption by 1098 mg/d, from 657 to 1755 mg/d.

These results showed that energy from sources other than added sugars had a stronger association with micronutrient intake than did energy from added sugars.

DISCUSSION

The use of %E_{AS} as the key variable in the analysis presented in the IOM study makes it impossible to separate the association of added sugars on micronutrient consumption from that of total energy or energy from other sources. Because total energy is the denominator of %E_{AS}, total energy and %E_{AS} are strongly related. Total energy is also strongly related to consumption of micronutrients. These statistical problems are not unique to the use of %E_{AS}. Constructing a variable that is the percentage energy of any macronutrient raises difficult interpretation issues.

Reanalysis of the data using the alternative statistical approach of energy decomposition reveals that energy from sources other than added sugars has a much stronger, positive, and more consistent relation with consumption of micronutrients than does energy from added sugars, which has a weak and inconsistent relation that is much smaller in magnitude.

Our reanalysis affirms that individuals must consume a balanced and varied diet that meets their nutritional needs and allows them to maintain a healthy weight. Focusing on added sugars in the diet and %E_{AS} in particular has little or no substantive effect on diet quality.

ACKNOWLEDGMENTS

The authors appreciate the cooperation and commitment of ENVIRON for making the data available for review and replication. The authors thank their colleagues at the Center for Food and Nutrition Policy. Ms. Patricia Anderson provided helpful comments on the draft of the manuscript and Ms. Gayle L. Hein assisted in the preparation of the tables and graphs.

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