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Factor Analysis Reduces Complex Measures of Nutrition Environments in US Elementary and Middle Schools into Cohesive Dimensions in the Healthy Communities Study

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ABSTRACT

Background: Although it has been recommended that schools be the hub of efforts to improve child nutrition, research describing school nutrition environments in US public schools and their associations with child health is limited.

Objective: This study aimed to evaluate the applicability of factor analysis methods to characterize school nutrition environments by identifying underlying factors, or dimensions, in the observed data and to examine the relation between school nutrition environment dimensions and child anthropometric and dietary outcomes.

Methods: This study examined a cross-sectional sample of 4635 US children aged 4–15 y from 386 US elementary and middle schools from the Healthy Communities Study (2013–2015). Data collected from schools were used to create 34 variables that assessed the school nutrition environment. To identify dimensions of school nutrition environments, exploratory factor analysis was conducted with orthogonal rotation, and factor scores were derived using methods to account for sporadic missing data. Mixed-effects regression models adjusted for child- and community-level variables and clustered by community and school examined the associations of school nutrition environment dimensions with child anthropometric and dietary outcomes.

Results: Six dimensions of school nutrition environments were derived: nutrition education, food options, wellness policies, dining environment, unhealthy food restriction, and nutrition programs. The unhealthy food restriction dimension was negatively associated with added sugar intake ($\beta = -1.13$, $P < 0.0001$), and the wellness policies dimension was positively associated with waist circumference ($\beta = 0.57$, $P = 0.01$).

Conclusions: This study demonstrates how factor analysis can reduce multiple measures of complex school nutrition environments into conceptually cohesive dimensions for purposes of assessing the relation of these dimensions to student health-related outcomes. Findings were mixed and indicate that the restriction of unhealthy foods in school is associated with lower added sugar intake. Additional, longitudinal studies are needed to substantiate the utility of this method for identifying promising school nutrition environments. *J Nutr* 2021;151:1286–1293.

Keywords: school nutrition environment, factor analysis, diet, school-age child, child, food environment, school meals

Introduction

For decades, schools have been a major source of food for US children (1). Whether eating lunch provided in the cafeteria or purchasing snacks from school fundraisers, children consume as much as half of their daily energy at school (2). Consequently, the school food environment, which consists of a collection of policies, practices, and physical attributes that may influence children's eating behavior at school, plays an important role in determining children's diets.

Interventions in school food environments have resulted in increased fruit and vegetable consumption and decreased consumption of sugar-sweetened beverages, saturated fat, sodium, and unhealthy snacks but have shown limited evidence of reducing obesity among students (3). Likewise, a review of school food programs and policies, including competitive foods standards and nutritional quality standards for school lunch and breakfast, found strong evidence that food environment changes under the Healthy, Hunger-Free Kids Act of 2010 (HHFKA) improved children's diets and eating behavior at

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school; however, research on weight outcomes was minimal and limited to subpopulations of students or examined individual variables of the school food environment, such as the dining environment or competitive foods (3, 4).

Food environments are complex and experienced through combinations of many variables that are potentially highly correlated. A method is needed that can assess the numerous aspects of the school food environment and determine which are most influential on child diet and weight outcomes. Inference using high-dimensional data can be challenging, and data reduction is a useful method to create meaningful predictor variables needed for inference models. These methods identify patterns within large sets of variables and transform the data into fewer, more informative variables that can explain variation in complex data. One such method, factor analysis, is useful for assessing food environments because it is able to identify latent, or unmeasured, factors underlying observed environmental characteristics.

Researchers have used data reduction techniques, such as structural equation modeling and principal component analysis, to study children's dietary patterns (5), investigate home food environments (6–10), or explore limited aspects of school food environments (11, 12), but no studies have used factor analysis to conceptualize the multidimensional aspects of school food environments and assess their relation with children's diet and anthropometric outcomes. Other studies involving schools, including an Australian study comparing the school food environment, assessed as a single composite variable, and home food environment, used structural equation modeling and found that a healthier school food environment was associated with improved child diet but was not associated with changes in BMI (11). In a study of schools in Canada where exploratory factor analysis was used to assess the role of perceived adequacy of school facilities and staff capacity in supporting implementation of school nutrition policies, results suggested that schools with above-average facilities had higher odds of adhering to lunch nutrition policies (12).

Although it has been recommended that schools be the hub of efforts to improve child nutrition (4), research describing school nutrition environments in US public schools and their associations with child health is limited. The first objective in this study was to evaluate the applicability of factor analysis methods to characterize school nutrition environments by identifying underlying relations, or dimensions, in the observed data. The second objective was to explore the relation between the dimensions and child anthropometric and dietary outcomes. Findings from this study can be used to inform public health practitioners on the influence different dimensions of the school nutrition environment can have on student outcomes and may aid decision makers in setting intervention priorities.

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Supplemental Tables 1–5 and Supplemental Figure 1 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/jn/.

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Abbreviations used: DSQ, Dietary Screener Questionnaire; HCS, Healthy Communities Study; HHFKA, Healthy, Hunger-Free Kids Act of 2010; NCI, National Cancer Institute.

Methods

Participants

The Healthy Communities Study (HCS) was a cross-sectional observational study of children aged 4–15 y in elementary school (typically between ages 5 and 10 y) and middle school (typically between ages 11 and 13 y) in 130 communities across the South, West, Midwest, and Northeast of the United States (13). Data from a sample of students, their households, schools, and communities were collected from 2013 through 2015 (14, 15). The overarching aim of HCS was to assess the relation between community programs and policies and child health. Communities, defined as public high school catchment areas, were selected using a stratified probability-based sample to ensure diverse demographics, programs, and policies, as well as a purposeful sample of communities identified as having innovative or promising programs and policies. Up to 2 elementary and 2 middle schools were selected within each community; selection was based on how well the student population matched the demographic profile of the given community, and all grade-eligible children were invited to participate (14, 15). The Battelle Memorial Institutional Review Board approved the study protocol. Consent information was included and obtained in the surveys completed by school personnel. Written informed consent for each participating child was obtained from a parent or guardian, and written assent was obtained from children.

School nutrition environment

Three complementary instruments were used to assess the school nutrition environment in each study school (16). From these tools, school nutrition environment variables were derived (**Supplemental Table 1**). Information was collected by observing school lunch foods and competitive foods available on campus during 1 school lunch period. Information about school foodservice that could not be observed was collected by a survey completed by the district foodservice director or designee, including school participation in selected state and federal nutrition programs (e.g., Fresh Fruit and Vegetable Program, Healthier US School Challenge, Team Nutrition, and Farm to School) and adherence to district food-related school wellness policies (e.g., reimbursable school meal goals, competitive foods, and nutrition guidelines for classroom and event foods). Information about nutrition education and school wellness committee was collected by a survey completed by the school staff person designated by the school principal to serve as the study liaison. Several variables, including number of different types of vegetables offered in reimbursable lunch, number of different types of fruits offered in reimbursable lunch, and number of competitive food venues, were divided by total student enrollment to account for school size.

Child and household measures

The HCS study included assessment of child dietary intake, anthropometry, physical activity, and demographics. Trained field data collectors conducted home visits to collect household- and child-level data. The visit included a household survey, which was completed by a primary respondent determined by the child's age: parent/adult caregiver proxy for children 4–8 y old with child assistance, children 9–11 y old with adult assistance, and children 12–15 y old with input from adult only if needed. Demographic questions were answered by the parent/adult caregiver and included items such as parent educational attainment, employment status, race, ethnicity, and household income (15).

Anthropometric measures

Child height, weight, and waist circumference were measured during the in-home visit by trained data collectors according to protocols adapted from procedures used in the NHANES (17). BMI z scores were calculated from height and weight measurements using CDC age- and sex-specific growth charts.

Dietary intake

Dietary intake was assessed using the NHANES Dietary Screener Questionnaire (DSQ) developed by the National Cancer Institute (NCI).

The DSQ was administered during the in-home visit by a trained data collector. Respondents were asked to report their frequency of intake of select foods over the past 30 d. Publicly available NCI scoring algorithms were then used to convert frequencies into estimated quantities of foods consumed for fruit/vegetables/legumes (cups/d), added sugar (g/d), and whole grains (g/d). Dietary outcomes examined were limited to those with previously established associations with obesity to minimize the potential for spurious findings (18–20).

Statistical analysis

A 2-stage analysis was conducted to first extract dimensions of the school nutrition environment factors using exploratory factor analysis and then to examine how these dimensions were related to child health outcomes using mixed-effects regression. Exploratory factor analysis using the PROC FACTOR procedure in SAS software (version 9.4; SAS Institute) was conducted to describe and understand the relations among numerous school nutrition environment variables. In this process, variables are combined into dimensions, which consist of subsets of variables that are correlated with one another but are relatively independent of other subsets. These dimensions are considered to reflect underlying processes that create the patterns of correlations and describe the school nutrition environment (21). An iterated principal factor analysis with orthogonal (varimax) rotation, which derived noncorrelated dimensions, was performed. Results were similar when using oblique (promax) rotation, and interfactor correlations were low, with all <0.24 in magnitude (**Supplemental Tables 2** and **3**). Therefore, we used the factors from the orthogonal rotation. The initial analysis was conducted on 35 school nutrition environment variables; 1 variable examining the presence of indoor dining was not retained due to lack of variability across study schools. The final analysis included 34 school nutrition environment variables (Supplemental Table 1). To simplify interpretation of results, coding was structured so that variables were framed in a positive direction. For example, a positive dining ambiance and absence of chips/fries served with a reimbursable school lunch were both coded as 1, as opposed to 0. Schools that were missing >25% school nutrition environment variables were excluded from analysis ($n = 36$). The remaining missing data may have been due to the complexity of the data collection process and were considered missing at random. To account for this, mean imputation was conducted, a method of addressing random missing data in factor analyses (22, 23). The final analytical sample consisted of 386 schools. The Kaiser–Meyer–Olkin value (0.66) indicated sampling adequacy for factor analysis (21).

Confirmatory factor analysis using the PROC CALIS procedure in SAS software (version 9.4; SAS Institute) was conducted using the 6-factor structure that emerged from the exploratory factor analysis, resulting in a root mean square error of approximation (RMSEA) estimate of 0.06 and a standardized root mean square residual (RMR) of 0.06, indicating that the 6-factor structure fits the data. As an additional confirmation of the factor structure, the sample was randomly split in half, and exploratory factor analysis was conducted on one half. The resulting factor structure was similar to the one derived from the full sample. Confirmatory factor analysis was then conducted in the second half of the data set, and again, the RMSEA estimate of 0.06 and standardized RMR of 0.08 indicated good fit.

Factor analysis requires selection of the number of dimensions to retain. Retention of number of dimensions was based on eigenvalues, which indicate the magnitude of variation in the full data set associated with a dimension; visual inspection of the scree plot; and interpretability of the dimensions, involving assessment of which set of dimensions meaningfully described school nutrition environments (**Supplemental Table 4**, **Supplemental Figure 1**) (21, 24). Solutions ranging from 3 to 7 dimensions were examined and resulted in the retention of 6 dimensions (**Supplemental Table 5**). Variables with factor loadings, the correlation between the variables and factors, with a value ≤–0.3 or ≥0.3, were considered important for interpretation (21). Factor loadings with a positive value can be interpreted as being positively correlated with the factor and vice versa. Dimensions were labeled by authors according to the variables that loaded most heavily on each one. Analyses conducted with the imputed and nonimputed data set yielded similar results.

In the second stage of analysis, factor scores for each of the derived dimensions were calculated for each child and used as independent variables in a mixed-effects regression on child anthropometric and dietary outcomes. The analytical sample had 4635 children. Models were adjusted for child- and community-level variables and adjusted for clustering by community and school. For BMI z score and waist circumference outcomes, child-level covariates were annual household income, child height, maximum paternal education, maximum maternal employment, ethnicity, sex, and age polynomials, as well as community-level covariates of US region and minority classification (≥30% black or Hispanic), calculated from the 2009–2013 American Community Survey (14). For dietary intake outcomes, child-level covariates were annual household income, maximum parental education, maximum parental employment, race/ethnicity, and seasonality; community-level covariates included US region, minority classification, urbanicity, percent population black, percent population Hispanic, percent population below poverty, and percent population unemployed. Covariates were selected based on least absolute shrinkage and selection operation operator techniques (25). In addition, to account for missing information, multiple imputation was used, and results were integrated across 20 imputed data sets (26). Data were analyzed using SAS 9.4 (SAS Institute); $P < 0.05$ was considered statistically significant.

Results

Of the 386 schools in the analytical sample, over half were elementary schools (54%), over one-third were middle schools (35%), and the remaining were combination elementary and middle schools (11%). Mean student enrollment per school was 639 students. Approximately three-fourths of schools were located in suburban (42%) or urban (35%) communities. Schools were distributed across the South (44%), West (22%), Midwest (18%), and Northeast (16%).

Six school nutrition environment dimensions were derived and labeled as follows: nutrition education, food options, wellness policies, dining environment, unhealthy food restriction, and nutrition programs. These dimensions explained 39.1% of the total variance in the school nutrition environment data. The nutrition education dimension was strongly associated with 4 variables—implementation of sequential nutrition education for all grade levels, specified hours of nutrition education, standards-based nutrition education, and implementation of nutrition education goals—and moderately associated with having a nutrition education review team and regular school wellness council meetings (**Table 1**). The food options dimension included number of vegetable types offered in reimbursable lunches, number of fruit types offered in reimbursable lunches, and a greater number of competitive food venues. The wellness policy dimension included implementation of 2 school wellness policies: nutrition guidelines for competitive foods and nutrition guidelines for classroom and event foods. The dining environment dimension included dining ambiance, time in line for lunch, dining area size, level of dining area crowding during lunch, Department of Defense Fresh Fruit and Vegetable program participation, and fewer whole-grain products in reimbursable lunches. The unhealthy food restriction dimensions consisted of compliance with competitive food standards and the absence of free chips/fries with reimbursable school lunch. Finally, the nutrition programs dimension includes participation in the Healthy US School Challenge, Farm to School Program, Fresh Fruit and Vegetable Program, and the USDA Team Nutrition Initiative. Eleven variables that did not meet the factor loading threshold (magnitude <0.30)—having a school wellness coordinator, implementation of reimbursable school meal goals,

TABLE 1 Factor loadings for school nutrition environment dimensions from exploratory factor analysis of schools in the Healthy Communities Study using orthogonal rotation[1]

Factor	Variable name	Factor loading[2]
1) Nutrition education	Implementation of sequential nutrition education for all grade levels	0.876
	Specified hours of nutrition education	0.823
	Standards-based nutrition education materials	0.794
	Implementation of nutrition education goals	0.737
	Nutrition education review team	0.697
	Regular school wellness council meetings	0.456
2) Food options	Number of vegetable types in reimbursable lunch	0.725
	Number of fruit types in reimbursable lunch	0.674
	Fewer competitive food venues	−0.518
3) Wellness policies	Nutrition guidelines for competitive foods	0.806
	Nutrition guidelines for classroom and event foods	0.657
4) Dining environment	Positive dining ambiance	0.505
	Efficient lunch line for lunch	0.389
	Sufficient dining area size	0.360
	Noncrowded dining area	0.349
	Department of Defense Fresh Fruit and Vegetable program participation	0.344
	Whole-grain products in reimbursable lunch	−0.305
5) Unhealthy food restriction	Competitive foods compliance	0.620
	Absence of chips/fries with reimbursable lunch	0.334
6) Nutrition programs	Healthier US School Challenge participation	0.596
	Farm to School Program participation	0.415
	Fresh Fruit and Vegetable program participation	0.330
	USDA's Team Nutrition Initiative participation	0.317

[1]Variables with factor loading magnitude <0.30 are excluded from the table.
[2]Factor loadings are a measure of correlation between the variables and factor. Factor loadings with the more positive values can be interpreted as being more positively correlated with the factor and vice versa.

scratch cooked lunches, non-fast-food entrees in reimbursable lunch, sufficient lunch period length, absence of dessert/snack with reimbursable lunch, pleasant staff–student interactions, absence of sugar-sweetened beverages with reimbursable lunch, healthier milk options with reimbursable lunch, number of water sources in the dining area, and salad with reimbursable lunch—were not considered in the interpretation of dimensions.

The analytical sample for the mixed-effects linear regression consisted of 4635 students (**Table 2**). The sample was evenly split by sex (50% female), and the average age of participants was 9.3 y. The 2 largest race/ethnicity groups were Hispanic (45%) and non-Hispanic white (31%), followed by non-Hispanic black, other, and multiracial. Half of the sample had a household income of <\$35,000 (51%). The largest group of participants were from the South (43%), followed by the West (24%), the Midwest (17%), and the Northeast (17%).

From the regression analysis between the 6 school nutrition environment dimensions and child health measures, the unhealthy food restriction dimension was negatively associated with child added sugar intake ($\beta = -1.13$, $P < 0.0001$) (**Table 3**). The school wellness policies dimension was positively associated with child waist circumference ($\beta = 0.57$, $P = 0.01$). There were no other significant associations, although the food options dimension had a positive association with added sugar intake that neared significance ($\beta = 0.39$, $P = 0.05$).

Discussion

This study contributes to the limited evidence base on school nutrition environments in diverse US communities and their associations to children's health. It also uses a technique—exploratory factor analysis—that, to our knowledge, has not yet been applied to assess the multidimensionality of school nutrition environments. This method has the advantage of using a data-driven process to transform a large number of variables into groupings of correlated variables to explain the variance in the data rather than using index scores or a priori variable selection, methods that are more commonly used to assess nutrition environments (27, 28). Results have the potential to inform decision makers and public health practitioners on the influence that different aspects of the school nutrition environment can have on student outcomes. Because opportunities for intervention in school settings are numerous and multifaceted, yet may be resource intensive, this method can aid decision makers in setting priorities.

The use of factor analysis allowed numerous measures of school nutrition to be reduced and grouped into 6 dimensions of the school nutrition environment. Dimensions consisted of variables that may have been driven by a common underlying process. For example, all the variables in the nutrition education dimension were related to nutrition education. This suggests that the schools that offer quality nutrition education in regard to one variable also tend to rate similarly high on the other nutrition education quality variables. Similar cohesiveness was apparent for the other dimensions. The 6 resulting dimensions—nutrition education, food options, wellness policies, dining environment, unhealthy food restriction, and nutrition programs—reflect focus areas for school interventions (16, 29).

In some cases, not all variables in a dimension were conceptually related, suggesting they may group together based on other commonalities. For example, within the dining environment dimension, although the 4 variables with the highest factor loading were direct measures of dining environment, the 2 variables with lower factor loadings—Department of Defense Fresh Fruit and Vegetable program

TABLE 2 Characteristics of children in the Healthy Communities Study ($n = 4635$)[1]

Characteristic	Value
Child level	
Age, y	9.3 (2.7)
Sex, female, *n* (%)	2336 (50.4)
Race/ethnicity, *n* (%)[2]	
Hispanic or Latino	2064 (44.5)
Non-Hispanic white	1428 (30.8)
Non-Hispanic black	799 (17.2)
Non-Hispanic multiracial	165 (3.6)
Non-Hispanic other	179 (3.9)
Household annual income, *n* (%)	
<\$20,000	1226 (26.5)
\$20,000 to \$35,000	1122 (24.2)
\$35,000 to \$50,000	585 (12.6)
\$50,000 to \$75,000	518 (11.2)
\$75,000 to \$100,000	373 (8.1)
>\$100,000	811 (17.5)
Maximum parental education from either biological parent, *n* (%)	
Less than high school	1034 (22.3)
High school diploma or equivalent	936 (20.2)
Some college or associate degree	1177 (25.4)
Bachelor's degree	719 (15.5)
Graduate degree[3]	769 (16.6)
Maximum current employment status of either biological parent, *n* (%)	
Working full-time for pay	3398 (73.3)
Working part-time for pay	451 (9.7)
Unemployed[4]	246 (5.3)
Other	540 (11.7)
School type, *n* (%)	
Elementary school	2888 (62.3)
Elementary and middle school	489 (10.6)
Middle school	1258 (27.1)
Child anthropometric measures	
BMI *z* score	0.68 (1.21)
Waist circumference, cm	69.53 (14.99)
Dietary intake[5]	
Fruit, vegetable, and legume intake, cups/d	2.57 (0.90)
Added sugar intake, g/d	76.32 (31.24)
Whole-grain intake, g/d	20.16 (12.04)
Community level	
US region, *n* (%)	
Midwest	775 (16.7)
Northeast	774 (16.7)
South	1980 (42.7)
West	1106 (23.9)
Urbanicity	
Rural	1130 (24.4)
Suburban	1893 (40.8)
Urban	1612 (34.8)
Community minority classification, *n* (%)[5]	
Black	887 (19.1)
Hispanic	1872 (40.4)
Other	1876 (40.5)

[1]The number of observations may vary due to nonresponse. Values are mean (SD) unless otherwise indicated.
[2]Race and origin: Other includes American Indian/Alaska Native, Native Hawaiian/Pacific Islander, and Asian.
[3]Graduate includes master's, professional, and doctorate degree.
[4]Unemployed includes temporarily laid off, on sick leave or maternity leave, looking for work, and unemployed; Other includes disabled, keeping house, retired, student, and other.
[5]Classification based on communities consisting of ≥30% black or Hispanic populations.

TABLE 3 Associations between school nutrition environment dimensions and child anthropometric and dietary outcomes of children in the Healthy Communities Study

Characteristic	Estimate (SE)	*P*
BMI *z* score[1] ($n = 4635$)		
Nutrition education	−0.01 (0.02)	0.47
Food options	0.01 (0.02)	0.82
Wellness policies	0.04 (0.03)	0.10
Dining environment	0.04 (0.03)	0.09
Unhealthy food restriction	0.02 (0.03)	0.54
Nutrition programs	0.00 (0.03)	0.91
Waist circumference[1] ($n = 4596$)		
Nutrition education	0.03 (0.20)	0.88
Food options	−0.12 (0.25)	0.65
Wellness policies	0.57 (0.23)	0.01
Dining environment	0.09 (0.25)	0.73
Unhealthy food restriction	0.24 (0.26)	0.37
Nutrition programs	−0.14 (0.26)	0.60
Fruit, vegetables, and legumes intake[2] ($n = 4635$)		
Nutrition education	−0.03 (0.02)	0.12
Food options	0.02 (0.02)	0.44
Wellness policies	−0.01 (0.02)	0.64
Dining environment	−0.02 (0.02)	0.45
Unhealthy food restriction	0.00 (0.02)	0.92
Nutrition programs	0.01 (0.02)	0.58
Added sugar intake[2] ($n = 4635$)		
Nutrition education	0.06 (0.15)	0.71
Food options	0.39 (0.20)	0.05
Wellness policies	0.28 (0.18)	0.13
Dining environment	−0.13 (0.20)	0.50
Unhealthy food restriction	−1.13 (0.19)	<0.0001
Nutrition programs	−0.10 (0.21)	0.64
Whole-grains intake[2] ($n = 4635$)		
Nutrition education	0.00 (0.01)	0.76
Food options	0.00 (0.01)	0.79
Wellness policies	0.00 (0.01)	0.79
Dining environment	−0.01 (0.01)	0.26
Unhealthy food restriction	0.01 (0.01)	0.21
Nutrition programs	0.01 (0.01)	0.42

[1]Mixed-effects linear regression adjusted for child-level (annual household income, child height, maximum paternal education, and maximum maternal employment, ethnicity, sex, age polynomial) and community-level variables (US region, minority classification). SEs accounted for clustering at the community and school levels. Statistical significance at $P < 0.05$.
[2]Mixed-effects linear regression adjusted for child-level (annual household income, maximum parental education, and maximum parental employment, race/ethnicity, seasonality) and community-level variables (US region, minority classification, urbanicity, percent population black, percent population Hispanic, percent population below poverty, percent population unemployed). SEs accounted for clustering at the community and school levels. Statistical significance at $P < 0.05$.

participation and proportion of whole grains products served—were not. These variables may group together because they are likely controlled by a common decision maker, in this case, the school nutrition director. A director who places priority on an appealing dining environment may also be innovative in terms of other meal service improvements. Similarly, variables contributing to the food options dimension (number of types of fruits and vegetables in reimbursable lunches and number of competitive food venues) are also both likely influenced by the school nutrition director but, in this case, perhaps by directors who focused on increasing healthy food options. On the other hand, variables contributing to the unhealthy food restriction dimension (competitive foods compliance and absence of chips/fries with reimbursable lunches) were closely tied to public policy changes that limit unhealthy options, such as the HHFKA. The HHFKA set nutrition standards for competitive foods and changed meal patterns for school meals to limit starchy vegetables, such as fries, among other provisions (30).

Two school nutrition environment dimensions were associated with child dietary intake or anthropometric outcomes. First, school nutrition environments with greater restriction on unhealthy foods were associated with lower consumption of total added sugar by students. The 2 variables that most contributed to the unhealthy food restriction dimension, through positive factor loadings, were compliance of competitive foods available during the lunch period and absence of chips and fries with reimbursable lunches. Because the competitive food standards include limits on the sugar content of foods and sugar-sweetened beverages, this association is not surprising. Although absence of chips and fries as part of the reimbursable lunch would not directly affect sugar intake, because sugar content of meals was not measured, it may be a marker of an overall healthier array of foods offered and a focus by the school to limit less healthy options. A third variable, implementation of reimbursable school meal goals, also loaded highly on this dimension with a factor loading of 0.29. Although it was not included in Table 1 due to the magnitude $\geq$0.30 cutoff used, this suggests that reported implementation of reimbursable school meal goals is associated with observed measures of a healthier school food environment. The added sugar outcome reflects overall daily consumption, highlighting the potential influence of school nutrition practices to influence children's overall diets. This result is consistent with previous studies, which have found competitive food standards are effective in decreasing sugar, fat, and energy consumed and in limiting BMI change among adolescents (31, 32). Another study of food environments found that offering French fries and similar products in reimbursable school meals was negatively associated with student health (28).

Second, implementation of school wellness policies was associated with higher student waist circumference, which ran counter to expectations that school wellness policy implementation would be associated with favorable outcomes. This finding is also contrary to previous research that showed that school wellness committee meeting frequency was associated with lower BMI *z* scores in the same study population (33). A possible explanation for this counterintuitive result is that schools with a higher-risk student population may have a stronger motivation to implement wellness policies. A study of Utah school districts found that schools serving students most vulnerable to obesity had the strongest wellness policies (34). In another study of US middle schools, decreased availability of low-nutrient, energy-dense à la carte foods was positively associated with BMI among students (28). Furthermore, waist circumference is a long-term outcome, and any benefits of school wellness policy implementation may not yet have been realized. Because HCS was a cross-sectional observational study, it was not possible to assess changes over time or to separate social causation from social selection.

The food options dimension also had a positive association with added sugar intake that neared significance. The food options dimension was composed of a positive loading for number of fruits and vegetables offered in the reimbursable school lunch (where a more positive loading value indicates more options) and negative loading for fewer competitive food venues (where a more negative loading value indicates more venues). Although an increase in the number of fruits and vegetables offered in the reimbursable school lunch would not be expected to increase added sugar intake, the association may be driven by the greater number of competitive food venues.

Overall, there were limited associations between the school nutrition environment dimensions and child outcomes. Child diet and weight are influenced by multiple elements over time, with school environments being just one of them (35). Preventing obesity may require more comprehensive interventions and sensitive longitudinal measures due to its complex and long-term nature (35). Furthermore, extensive changes to the school environment over several years may be needed to produce measurable impact (36, 37). Naturally occurring differences in school environments as observed in this study may not have been adequately extensive, and the information regarding length of exposure to these environments was not available. In addition, given that over half of the children's energy intake comes from sources outside of school meals (2), opportunities to improve dietary intake outside of school settings should also be explored.

This study has several limitations. Due to the cross-sectional study design of HCS, causality could not be inferred. It is possible that local school wellness policies are implemented in response to high need in the student population. Regardless, the identification of intervention focus areas of school nutrition environment and their relative associations to child health is important to consider when designing school nutrition interventions. The study also did not capture the long-term effects of implementing the school nutrition program and policies. Future studies could incorporate measures of duration of implementation and relation to subsequent anthropometric outcomes that may require longer-term exposure to favorable environments. In addition, although many of the measures were obtained through observation, the school wellness policy measures were self-reported by a school staff member and could be challenging to report accurately and subject to response bias. Future analyses could examine reported levels of wellness policy implementation together with observed measures of implementation. Measures specific to school breakfast programming were also not captured. Finally, students in the sample were not selected to be representative of their school. Although schools were selected to be demographically representative of the community, it is possible that results could be affected by participation bias. HCS was not intended to be nationally representative, and it is not clear if associations would have differed if students were representative of their schools. The exploratory factor analysis method itself also posed limitations, as the selection of number of dimensions extracted is ultimately based on judgment. Although eigenvalues, scree plots, and interpretability were used to guide investigators in determining the best solution and resulting dimensions were consistent with areas of school nutrition environment identified by other studies (16, 29), reproducibility of this method with other similar data sets is needed.

This study also had several strengths. HCS provided a large data set with many variables that comprehensively measured various aspects of the school nutrition environment using observational methods in addition to self-report. Factor analysis is a large sample technique, requiring adequate sample size, number of variables, and size of factor loadings to reproduce a population pattern and obtain a robust factor model (38). The size and nature of the HCS data set was suitable for factor analysis. Another strength of this study was the ability to simultaneously assess multiple aspects of school nutrition environments by including all dimensions in the regression models with child health outcomes. This allowed the examination of the relative influence of the various aspects of school nutrition environments.

This study demonstrates how factor analysis can be used to make sense of complex, detailed measures of school nutrition environments and produce interpretable results to inform policy makers, school administrators, and those who design and implement school nutrition programs and policies. Although findings were mixed with school wellness implementation and waist circumference, this study indicates that providing fewer unhealthy options consistent with the HHFKA, such as items offered in competitive foods and reimbursable meal foods, is associated with healthier dietary intake among students. These findings reinforce what other studies (36, 39) have concluded regarding the importance of sustaining progress made in terms of the implementation of school meal and competitive food standards. Future studies should incorporate these types of novel data reduction methods when examining longitudinal school nutrition measures with various health outcomes.

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