Genetic and shared environmental influences on children’s 24-h food and beverage intake: sex differences at age 7 y

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ABSTRACT

Background: The genetics of habitual food and beverage intake in early childhood is poorly understood.

Objective: The objective was to test the magnitude of genetic and environmental influences on 24-h food and beverage intake in 7-y-old children. The association between intake of specific food-beverage categories and child body mass index (BMI; in kg/m²) was also tested.

Design: A classic twin design was conducted, using the MacArthur Longitudinal Study of Twins. There were 792 children, including 396 boys from 102 monozygotic and 96 dizygotic twin pairs and 396 girls from 112 monozygotic and 86 dizygotic twin pairs; Children’s 24-h dietary intake was estimated by parental recall, from which 9 composite food-beverage categories were derived. Height and weight were converted to BMI. Biometrical analyses of children’s daily intake of food-beverage categories and BMI were conducted.

Results: There was consistent evidence of genetic influences on children’s 24-h intake of food and beverages (servings/d), especially among boys. Seven categories showed significant heritability estimates among boys, ranging from 12% (fish and lemon) to 79% (peanut butter and jelly). Only 3 categories showed significant heritability estimates among girls, ranging from 20% (bread and butter) to 56% (fish and lemon). BMI showed a genetic correlation only with bread and butter intake in girls.

Conclusion: The magnitude of genetic and environmental influences on children’s 24-h food and beverage intake differed for boys and girls, which suggests sex differences in the development of eating patterns. Heritability estimates were generally large, although other eating phenotypes may be necessary for identifying genetic correlations with adiposity. Am J Clin Nutr 2008;87:903–11.

INTRODUCTION

There is considerable interest in the development of child eating patterns and food intake regulation (1), especially as related to establishment of a healthy diet. Overconsumption of energy relative to energy expenditure, even at modest daily energy surpluses, can promote childhood obesity (2, 3). Unprecedented concerns about childhood obesity as a public health disorder, along with concerns about its medical complications, have amplified interest in the establishment of eating styles early in life.

Experimental studies indicate that environmental factors can influence child eating behaviors (1, 4, 5). Child food preferences and intake can be influenced by the number of exposures to a target food (6), role modeling by other children or teachers (7–9), the work cost necessary to access foods (10), restriction of foods (11), and food variety (12). These data speak to the role of environmental influences in child nutrition, at least in the short-term or when studied in controlled settings.

There also is accumulating evidence from animal experiments and adult twin studies that eating behavior is genetically influenced. Several adult twin studies have documented a heritable component to total and macronutrient intake (13–17), intake of individual foods and beverages (14), and broader food intake patterns (18). However, genetically informative designs rarely have been used to investigate child food and beverage intake. Studies have traditionally examined parent-child correlations (19–21) or sibling correlations (21, 22) for eating measures but, until recently (23, 24), have not disaggregated genetic and environmental influences. Genetically informative designs are necessary to address such questions, which are especially useful in the realm of child development (25). This is because, in addition to serving as role models, parents also transmit their DNA to offspring.

The classic twin design can be a powerful methodology for decomposing genetic, shared environmental, and nonshared environmental influences on a trait (26). Additive genetic influences refer to net influence of individual alleles that contribute additively to total variation in a trait. Shared environmental influences refer to shared aspects of the home environment for which siblings are perfectly correlated (eg, the number of high-fat snack foods in the home cupboards). Nonshared environmental influences refer to aspects of the environment for which siblings are uncorrelated (eg, differential interactions with family members or peers).

The present study used a classic twin design to test the magnitude of genetic and environmental influences on the 24-h food and beverage intake of 7-y-old boys and girls. We predicted both additive genetic and shared environmental influences on food-beverage intake categories. Genetic influences are suggested by

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extensive animal research (27) and the aforementioned adult twin studies (28, 29). The prediction for shared environmental influences also was based on adult twin studies (18, 30). Sex differences in the magnitude of genetic and environmental influences were also tested. A second aim of this study was to test whether children’s intake of composite food-beverage categories was associated with their body mass index. If so, bivariate biometrical models tested whether the association was due to common underlying genes (ie, a genetic correlation).

SUBJECTS AND METHODS

Subjects

This study was a secondary analysis of a longitudinal twin cohort established to investigate the interplay of genetic and environmental influences on child development (31, 32). Data from this cohort have been used to address a number of topics in children across the domains of temperament, emotion, and cognition. Details of the sample were provided elsewhere (31). In brief, participating twins were same-sex twin pairs born in Colorado between 1986 and 1990, whose parents were initially contacted through a mass mailing sent out through the Colorado Department of Health. Parents who responded to the initial mailing and lived within a 3-h drive of the testing site in Boulder were invited to participate. More than 50% of the eligible families agreed to participate. More than half of the sample (63%) had participated in a previous infant twin study and were prospectively followed during their growth, although they were recruited in the same manner. Families understood that the overarching purpose of the study was to investigate genetic and environmental influences on various domains of development, including behavioral, cognitive, social, and family realms.

The 7-y evaluation trained parents to estimate their twins’ food and beverage intakes for the prior 24 h by using standardized dietary recall procedures (see below). The sample for the present study was 792 children, for whom dietary intake measures were ascertained: 396 boys from 102 monozygotic twin pairs and 96 dizygotic twin pairs and 396 girls from 112 monozygotic twin pairs and 86 dizygotic twin pairs.

For girls, the mean (±SD) age, weight, height, and BMI values were 88.68 ± 3.98 mo, 1.24 ± 0.06 m, 23.92 ± 4.19 kg, and 15.43 ± 0.19, respectively. For boys, the mean (±SD) age, weight, height, and BMI values were 89.64 ± 4.63 mo, 1.25 ± 0.06 m, 24.39 ± 4.07 kg, and 15.59 ± 1.63, respectively. All procedures were followed in accordance with the standards of the University of Colorado at Boulder and received institutional review board approval.

Zygosity

Twins were classified as being monozygotic or dizygotic on the basis of 11 highly polymorphic microsatellite genetic markers (33).

Body mass index

Most of the twins’ weights and heights were measured in the laboratory with a balance-beam scale and stadiometer, respectively; in a minority of children who did not come into the laboratory for these measurements, we ascertained weight and height at the children’s home using a bathroom scale and tape measure, respectively. We computed (BMI; in kg/m²), a well-established and validated measure of total body fat in pediatric samples (34). Although BMI is a crude estimator of total body fat because it measures both fat and fat-free mass, it is useful and valid for epidemiology studies.

24-h Food and beverage intake

Interviews with parents were conducted in person at the Institute for Behavioral Genetics, University of Colorado, to assess each twin’s dietary intake on the previous day. For a minority of families, the interviews were conducted at the participants’ homes because laboratory visits were not feasible for the families. Irrespective of the interview location, parents were asked to describe everything their twins had consumed, including beverages, for all meals and snacks during the previous 24 h, along with the number of servings consumed (serving sizes, for the purposes of this study, are defined below). Parents were instructed to provide their best estimates possible, through discussions with their twins, for any snacks or meals consumed when the parents were not present. Because there can be challenges in recalling the differential food and beverage intakes of twins in the same household, parents were encouraged to pay attention to the unique intakes of their 2 twins. Recalls were conducted separately for each twin, with the interviewers writing down foods and beverages on a form that had spaces for breakfast, lunch, and dinner and morning, afternoon, and evening snacks. Because the recalls corresponded to the 24-h period preceding the laboratory or home visit, assessments were not conducted on randomly determined days. Data collection occurred for a single 24-h period, on the day before the laboratory assessment. This day could have been a weekday or weekend. Children could have been eating at the home or school during this period. We note that this procedure did not involve a food-frequency questionnaire.

When reporting twins’ food and beverage intake, mothers were instructed to indicate how many servings of each item were consumed. The amount of food or beverage constituting one “serving” was defined by the investigators in advance, and these definitions were used consistently across all families. When conducting the recalls, parents were instructed to think of serving sizes in terms of these units. We note that mothers were not provided measuring scales, cups, or 2-dimensional posters to help with portion size estimation before the assessment visit; therefore, exact weights or volumes could not be obtained. This decision was made for 2 reasons. First, there were logistical barriers to providing these materials to families in advance and providing formal in-person portion size estimation training. Second, the investigators did not want to potentially bias the families’ dietary intake for the designated assessment day (eg, encourage “healthier” choices), which might have occurred if mothers knew that dietary intake would be assessed and by providing measurement supplies. For this reason, the mothers were not specifically told in advance that a complete food and beverage recall would be conducted on the assessment visit. There are tradeoffs to this approach, which we discuss below. Most notably, this approach does not permit ultimate computation of total or macronutrient-specific energy intake. Another limitation of the procedure is that the exact method of food preparation (eg, fried, broiled, or baked chicken cutlet) is not systematically recorded; therefore, accurate energy intake estimates could not be computed.

Serving sizes were operationalized as follows. For beef, chicken, and pork consumed as patties or cutlets, which is how
children consumed these items most frequently (eg, hamburger or chicken patty), one serving was defined as a single cutlet irrespective of the size or weight of the cutlet; for chicken off the bone, one serving was defined as a single section of meat (eg, leg and thigh or breast); for all breads, one serving was operationalized as a single slice; for all cereals, one serving was operationalized as one bowl; for jams and jellies, one serving was operationalized as one tbsp; for butter, one serving was operationalized as one pat; for candy bars and other candies, one serving was operationalized as a single bar or chunk; and for all beverages, one serving was operationalized as 1 cup. Thus, for all foods and beverages, the serving size unit was an ordinal variable; higher scores represented a greater number of items consumed.

Once all recalls were completed, research staff from the Institute for Behavioral Genetics carefully reviewed the lists of recalled foods and beverages and summarized them into the following 21 categories: milk; nonmilk dairy products; beef, pork, and lamb; poultry; fish; eggs; legumes (peanuts and peanut butter); butter and margarine; fruit juice, punch, and soda; citrus fruit; other fruit; jam and jelly; deep-colored vegetables; other vegetables; sweets; high-salt snack foods; breads; breakfast cereals; other cereals; and candy. For each child, the number of servings of foods and beverages within each category was tallied; higher scores represented a greater daily intake (servings/d) of the category. To derive more refined food-beverage categories, we conducted a principal components analysis (PCA) with varimax rotation. The PCA thus reduced the original categories to a smaller number of food-beverage categories, reflecting the natural “clusters” in which those items were consumed. Nine distinct and interpretable components were extracted based on the Scree test and the criterion of eigenvalues >1.0. These 9 components accounted for 61% of the variance among the individual items. We considered including items with smaller loadings; however, this did not enhance the interpretability of the component scales.

On the basis of the PCA results, we created 9 composite food-beverage categories, with any item with a factor loading >0.60 considered to load on the scale. The 9 derived scale scores were labeled as follows: peanut butter and jelly intake, breakfast cereal and milk intake, bread and butter intake, adjusted fruit intake, adjusted red meat and pork intake, vegetable intake, adjusted candy intake, fish and lemon intake, and high-salt snack food intake. The specific items that loaded onto the respective factor scores and how each factor score was computed are summarized in Table 1.

Two points should be noted regarding the computation of these subscales. First, 3 factor scores refer to “adjusted” intakes (ie, adjusted fruit intake, adjusted red meat and pork intake, and adjusted candy intake). We used this term because, in creating these factor scores, certain items loaded negatively onto the respective factors and therefore were subtracted from the positively loading items. In this regard, we consider the total factor scores to be “adjusted.” Second, 4 subscale scores (peanut butter and jelly intake, cereal and milk intake, bread and butter intake, and fish and lemon intake) were computed by averaging the items loading on the factor, whereas 4 subscale scores (adjusted fruit intake, adjusted red meat and pork intake, vegetable intake, and adjusted candy intake) were computed by summing the items loading on the factor. We averaged the former subscales because it arguably made more sense to consider one serving to be the joint intake of the constituent foods and beverages loading on the factor, consumed together as a unit. For example, a child who consumed one serving of peanut butter and one serving of jelly together arguably consumed one serving of “peanut butter and jelly” rather than 2 servings of “peanut butter and jelly.” The same thinking can be applied to cereal and milk, bread and butter, and fish and lemon. We underscore that the difference in averaging versus summing approaches to computing subscale scores only has implications for descriptive statistics, when presenting daily intake of food-beverage categories, but gives identical findings for all inferential analyses.

### Statistical analysis

Descriptive statistics for daily intake of food-beverage categories are presented as means, SEs, medians, and indexes of skewness (skew/SE <sub>skew</sub>), and kurtosis (kurtosis/SE <sub>kurtosis</sub>); <i>t</i> tests were used to compare boys and girls with respect to daily intake of the food-beverage categories monozygotic with dizygotic twin pairs.

### Table 1

Foods and beverages loading onto each of the factors and how each score was calculated

<table>
<thead>
<tr>
<th>Composite food-beverage category</th>
<th>Foods and beverages loading onto factor</th>
<th>Computation of subscale score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peanut butter and jelly intake (servings/d)</td>
<td>Legumes (peanuts and peanut butter); jam and jelly</td>
<td>Average items</td>
</tr>
<tr>
<td>Breakfast cereal and milk intake (servings/d)</td>
<td>Milk; breakfast cereal</td>
<td>Average items</td>
</tr>
<tr>
<td>Bread and butter intake (servings/d)</td>
<td>Breads; butter and margarine</td>
<td>Average items</td>
</tr>
<tr>
<td>Adjusted fruit intake (servings/d)&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Noncitrus fruit; fruit juice, punch, soda (reverse coded)</td>
<td>Sum items</td>
</tr>
<tr>
<td>Adjusted red meat and pork intake (servings/d)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Beef, pork, lamb, poultry (reverse coded)</td>
<td>Sum items</td>
</tr>
<tr>
<td>Vegetable intake (servings/d)</td>
<td>Deep-colored vegetables; other vegetables</td>
<td>Sum items</td>
</tr>
<tr>
<td>Adjusted candy intake (servings/d)&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Candy; sweets (reverse coded)</td>
<td>Sum items</td>
</tr>
<tr>
<td>Fish and lemon intake (servings/d)</td>
<td>Fish; citrus fruit</td>
<td>Average items</td>
</tr>
<tr>
<td>High-salt snack food intake (servings/d)</td>
<td>High-salt snack foods</td>
<td>NA&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup> Intake of solid fruit minus the intake of fruit juice, punch, and soda.

<sup>2</sup> Intake of beef, pork, and lamb minus the intake of chicken.

<sup>3</sup> Intake of candy minus the intake of high-sugar foods.

<sup>4</sup> NA, not available.
For each food-beverage category, we computed Pearson’s correlations among monozygotic and dizygotic twin pairs to determine whether identical twins were more similar than fraternal twins. Greater phenotypic similarity among monozygotic than among dizygotic twin pairs implies greater genetic influences on the trait. To estimate heritability formally, biometric analyses were conducted. Specifically, sex-specific univariate biometrical analyses tested the magnitude of genetic, shared environmental, and nonshared environmental influences on the composite food-beverage categories and BMI. Using conventional data analytic methods for the “classical twin design” (35), we tested how well the observed data fit 5 models. These competing models posited the influence of the following parameters in various combinations: additive genetic (A) influences, referring to the influence of multiple alleles that work additively to affect the trait; dominant genetic (D) influences, referring to the influence of multiple alleles at the same genetic locus that work multiplicatively (interactively) to affect the trait; shared environment (C) influences, referring to the influence of environmental life experiences that are perfectly shared or correlated among siblings; and nonshared environment (E) influences, referring to the influence of environmental life experiences that are unshared by or uncorrelated among siblings.

The following 5 nested biometrical models were tested: A-C-E (ie, additive genetic, shared environmental, and nonshared environment), A-D-E (ie, additive genetic, dominant genetic, and nonshared environment), A-E (ie, additive genetic and nonshared environment), C-E (ie, shared environment and nonshared environment), and E (ie, nonshared environment only). The chi-square statistic and Akaike Information Criterion (AIC) were used to evaluate the goodness-of-fit of each individual model. A nonsignificant chi-square value suggests that the data do not significantly deviate from the posited model and, hence, signifies a relatively “good” fitting model. A progressively lower AIC value signifies a progressively better fitting model. Hence, when evaluating the 5 competing biometric models, one traditionally looks to a nonsignificant model (based on the chi-square test) with the lowest AIC value as the “best-fitting” model. At the same time, there are no absolute criteria for a “good-fitting” model and so the competing models are generally compared relative to one another in terms of the chi-square test and the AIC.

The difference in fit between competing nested models was formally tested with a chi-square test. The difference in fit between chi-square values of the individual models is approximately distributed as chi square, which can be used to evaluate statistically whether the best-fitting parsimonious model provided a significantly worse fit than did models that included additional parameters. The absence of a significant chi-square value suggests that parameters dropped from the more parsimonious model were not significant.

Initial analyses formally tested for the invariance of parameter estimates across sex. For each respective food-beverage category, competing biometrical models evaluated whether the best-fitting models were attained when parameter estimates were constrained to be equal or free to vary across sex. The results (data not shown) indicated that the data were best fit by models that freed parameters to vary by sex for 6 of the 9 food-beverage categories (peanut butter and jelly intake, bread and butter intake, adjusted red meat and pork intake, adjusted candy intake, fish and lemon intake, and high-salt snack foods intake). For the 3 other food-beverage categories, the difference in model fit per the AIC index was negligible. Thus, sex-specific biometric analyses were conducted for all 9 food-beverage categories. All biometrical twin analyses were conducted with the Mx Software (36).

Sex-specific Pearson’s correlations tested whether daily intake of the 9 composite food-beverage categories was associated with child BMI. Separate t tests were conducted for children assigned as “twin 1” and “twin 2,” respectively, to avoid the dependency in the data structure (37). Twinship number (1 compared with 2) within families was randomly determined. As noted in Results, BMI showed a phenotypic correlation with only one food-beverage category (ie, bread and butter intake, in girls only). Bivariate biometric models (35) were subsequently used to test whether this association was due to an underlying genetic correlation ($r_g$), a nonshared environmental correlation ($r_e$), or both.

RESULTS

Descriptive statistics for food-beverage intake measures

Descriptive information for the 9 food-beverage categories, by sex and zygosity, is shown in Table 2. Independent t tests indicated that boys consumed significantly more peanut butter and jelly (0.39 compared with 0.30 servings/d; $P = 0.01$), bread and butter (1.58 compared with 1.33 servings/d; $P < 0.001$), and adjusted red meat and pork (0.90 compared with 0.56 servings/d; $P < 0.001$) than did girls, but significantly less cereal and milk (1.18 compared with 1.31 servings/d; $P = 0.02$) and adjusted fruit intake (0.24 compared with 0.66 servings/d; $P = 0.001$). There were no significant differences in daily intake of food-beverage categories as a function of zygosity, with the exception of a greater intake of fish and lemon by dizygotic than by monozygotic twins (0.29 compared with 0.21 servings/d; $P = 0.003$).

Biometric results for boys

Twin correlations for daily intake of the 9 food-beverage categories are shown by zygosity in Table 3 for boys. Correlations were greater among monozygotic than among dizygotic twin pairs for 8 of the 9 variables. The average twin-pair correlations were 0.76 and 0.63 for monozygotic and dizygotic twins, respectively.

Estimates for additive genetic ($a^2$), shared environmental ($c^2$), and nonshared environmental ($e^2$) influences on the composite food-beverage intake categories also are presented in Table 3. There were significant additive genetic influences on daily intake of 7 food-beverage categories, and heritability estimates ranged from 12% (fish and lemon intake) to 79% (peanut butter and jelly intake) (Figure 1). For 2 categories (vegetable intake and fish and lemon intake), the best-fitting models still provided a relatively poor fit to the data ($P < 0.05$ and AIC values $>0$); therefore, these findings should be interpreted cautiously.

For BMI, the data were best fit by a model positing additive genetic, dominant genetic, and nonshared environmental influences ($\chi^2 = 2.075$, df = 3, $P = 0.56$, AIC = −3.925). These parameters accounted for 0%, 75%, and 25% of the variance, respectively. BMI was not associated significantly with any
intake of any of the derived food-beverage categories among either twin group (P > 0.05).

### Biometric results for girls

Twin correlations for daily intake of the 9 food-beverage categories are shown by zygosity in Table 4 for girls. Correlations were greater among monozygotic than among dizygotic twin pairs for 6 of the 9 variables. The average twin pair correlations were 0.73 and 0.68 for monozygotic and dizygotic twins, respectively.

Three composite food-beverage categories (ie, bread and butter intake, adjusted candy intake, and fish and lemon intake) were best fit by models positing additive genetic, shared environmental, and nonshared environmental influences. Six composite food-beverage categories (ie, peanut butter and jelly intake, cereal and milk intake, adjusted fruit intake, adjusted red meat and pork intake, vegetables, and high-salt snack intake) were best fit by the models positing only shared and nonshared environmental influences. Table 4 presents the $a^2$, $c^2$, and $e^2$ parameter estimates for these food-beverage categories. Heritability estimates ranged from 20% (bread and butter intake) to 56% (fish and lemon intake) (Figure 1). For 2 categories (vegetable intake and fish and lemon intake) the best-fitting models still provided a relatively poor fit to the data (P values <0.05 and AIC values >0; therefore, these findings should be interpreted very cautiously.

For BMI, the data were best fit by a model positing additive genetic and nonshared environmental influences ($\chi^2 = 4.327$, df = 4, $P = 0.36$, AIC = −3.673). These parameters accounted for 88% and 12% of the variance, respectively.

BMI was positively associated with daily bread and butter intake among girls assigned as twin 1 ($r = 0.19$, $P = 0.01$), and there was a trend among girls assigned as twin 2 ($r = 0.13$, $P = 0.07$). Three bivariate biometric models evaluated the extent to which the association was due to genetic or nonshared environmental factors influencing both phenotypes: The first model allowed only for a genetic correlation ($\chi^2 = 15.803$, df = 14, $P = 0.33$, AIC = −12.197), the second model allowed only for a nonshared environmental correlation ($\chi^2 = 19.505$, df = 14, $P = 0.15$, AIC = −8.495), and the third model estimated both a genetic and nonshared environmental correlation ($\chi^2 = 15.394$, df = 13, $P = 0.28$, AIC = −10.606). Thus, the best-fitting model, judged by the AIC, was the first. The genetic correlation was $r_g = 0.28$; standardized parameter estimates are presented in Figure 2.

### Table 2

Mean (SE; median; skew/SE skew; kurtosis/SE kurtosis) intake of food-beverage categories (expressed as servings/d), by child sex and zygosity

<table>
<thead>
<tr>
<th>Food-beverage category and zygosity</th>
<th>Girls</th>
<th>Boys</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MZ</td>
<td>DZ</td>
</tr>
<tr>
<td>Peanut butter and jelly intake</td>
<td>0.34 (0.03; 0.00; 10.12; 12.73)</td>
<td>0.38 (0.04; 0.04; 6.47; 6.65)</td>
</tr>
<tr>
<td>Breakfast cereal and milk intake</td>
<td>0.25 (0.03; 0.00; 10.94; 12.64)</td>
<td>0.41 (0.04; 0.00; 8.37; 5.84)</td>
</tr>
<tr>
<td>Bread and butter intake</td>
<td>1.29 (0.05; 1.50; 0.24; −0.62)</td>
<td>1.21 (0.05; 1.00; 3.00; 1.30)</td>
</tr>
<tr>
<td>Vegetable intake</td>
<td>1.36 (0.07; 1.00; 11.88; 0.05)</td>
<td>1.53 (0.06; 1.50; 3.88; 1.96)</td>
</tr>
<tr>
<td>Adjusted fruit intake</td>
<td>0.72 (0.11; 0.00; 2.26; −0.53)</td>
<td>0.31 (0.13; 0.00; 4.29; 3.46)</td>
</tr>
<tr>
<td>Adjusted red meat and pork intake</td>
<td>0.60 (0.14; 0.00; 1.22; −1.38)</td>
<td>0.20 (0.13; 0.00; 2.35; 1.94)</td>
</tr>
<tr>
<td>Adjusted candy intake</td>
<td>0.55 (0.08; 1.00; 0.09; 0.94)</td>
<td>0.93 (0.09; 1.00; 2.56; 0.15)</td>
</tr>
<tr>
<td>Fish and lemon intake</td>
<td>0.60 (0.09; 1.00; −1.08; −0.15)</td>
<td>0.87 (0.10; 1.00; 2.00; 1.02)</td>
</tr>
<tr>
<td>High-salt snack food intake</td>
<td>1.62 (0.10; 1.00; 11.67; 22.92)</td>
<td>1.57 (0.10; 1.00; 9.12; 16.63)</td>
</tr>
<tr>
<td></td>
<td>1.46 (0.10; 1.00; 6.00; 4.23)</td>
<td>1.41 (0.09; 1.00; 8.08; 11.92)</td>
</tr>
<tr>
<td></td>
<td>−1.25 (0.10; −1.00; −3.47; 3.26)</td>
<td>−1.55 (0.10; −2.00; 0.28; −0.06)</td>
</tr>
<tr>
<td></td>
<td>−1.56 (0.12; −1.00; −2.88; 7.65)</td>
<td>−1.49 (0.12; −1.00; −5.32; 5.25)</td>
</tr>
<tr>
<td></td>
<td>0.22 (0.02; 0.00; 13.81; 24.51)</td>
<td>0.21 (0.02; 0.00; 9.09; 5.76)</td>
</tr>
<tr>
<td></td>
<td>0.25 (0.03; 0.00; 5.59; −0.54)</td>
<td>0.33 (0.03; 0.00; 6.98; 2.82)</td>
</tr>
<tr>
<td></td>
<td>0.92 (0.06; 1.00; 5.77; 1.93)</td>
<td>0.92 (0.06; 1.00; 5.89; 3.83)</td>
</tr>
<tr>
<td></td>
<td>0.94 (0.07; 1.00; 4.07; −0.37)</td>
<td>0.89 (0.06; 1.00; 6.30; 6.72)</td>
</tr>
</tbody>
</table>

1 MZ, monozygotic; DZ, dizygotic. MZ boys, n = 204; DZ boys, n = 193; MZ girls, n = 224; and DZ girls, n = 172. Independent t tests indicated that boys consumed significantly more peanut butter and jelly (0.39 compared with 0.30 servings/d; $P = 0.01$), bread and butter (1.58 compared with 1.33 servings/d; $P < 0.001$), and adjusted red meat and pork (0.90 compared with 0.56 servings/d; $P < 0.001$) than did girls, but significantly less cereal and milk (1.18 compared with 1.31 servings/d; $P = 0.02$) and adjusted fruit intake (0.24 compared with 0.66 servings/d; $P = 0.001$). There were no significant differences in daily intake of food-beverage categories as a function of zygosity, except for a greater intake of fish and lemon by DZ than by MZ twins (0.29 compared with 0.21 servings/d; $P = 0.003$).

2 Intake of solid fruit minus the intake of fruit juice, punch, and soda.

3 Intake of beef, pork, and lamb minus the intake of chicken.

4 Intake of candy minus the intake of high-sugar foods.
DISCUSSION

The main finding of the present study was evidence of genetic influences on children’s 24-h food and beverage intake. Seven of the 9 derived food-beverage categories showed additive genetic influences in boys, and heritability estimates ranged from 12% (fish with lemon) to 79% (peanut butter and jelly). Of the 3 food-beverage categories that showed significant genetic influences in girls, heritability estimates ranged from 20% (bread and butter) to 56% (fish and lemon). To our knowledge, this is one of the largest investigations to document genetic influences on the 24-h food and beverage intake of prepubertal children, which suggests that genes may contribute considerably to the familial resemblance for children’s eating patterns. This finding is in line with most realms of child development (31, 38), underscoring genetic contributions to behavioral traits that traditionally were ascribed to the exclusive realm of the home environment.

Noteworthy about the present findings was the magnitude of heritability estimates for certain food-beverage categories, which were relatively large for a quantitative eating phenotype. This may have been due in part to the fact that this phenotype pooled information from a 24-h time block rather than from a single meal or because global eating patterns were studied rather than total energy intake. Habitual food and beverage choices may be a more meaningful representation of how children take in energy in the free-living environment (39). The literature on the genetics of eating behavior in humans has been challenged by the lack of informative phenotypes (40). The present findings suggest that a potentially useful phenotype may be intake of food-beverage categories, just like those used in certain adult twin studies (18).

A second main finding of this study was evidence of sex differences in the magnitude of genetic and environmental influences on child food and beverage intake (Figure 1). Heritability estimates were generally larger for boys, whereas shared environmental influences were generally larger for girls; these findings support those of some previous investigations. de Castro (16) found significant differences in the 24-h eating patterns of same-sex adult twin pairs who continuously recorded food and beverage intake for 7 d. Specifically, beverage intake of females showed no genetic influence but was influenced by the shared environment; in contrast, beverage intake was heritable in males.


TABLE 3

<table>
<thead>
<tr>
<th>Category</th>
<th>(r_{(MZ)})</th>
<th>(r_{(DZ)})</th>
<th>(a^2)</th>
<th>(c^2)</th>
<th>(e^2)</th>
<th>(\chi^2)</th>
<th>(P)</th>
<th>AIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peanut butter and jelly intake</td>
<td>0.77</td>
<td>0.48</td>
<td>0.79</td>
<td>0.21</td>
<td>2.18</td>
<td>0.70</td>
<td>-5.82</td>
<td></td>
</tr>
<tr>
<td>Breakfast cereal and milk intake</td>
<td>0.36</td>
<td>0.33</td>
<td>0.34</td>
<td>0.66</td>
<td>3.51</td>
<td>0.48</td>
<td>-4.49</td>
<td></td>
</tr>
<tr>
<td>Bread and butter intake</td>
<td>0.72</td>
<td>0.70</td>
<td>0.57</td>
<td>0.25</td>
<td>4.42</td>
<td>0.22</td>
<td>-1.58</td>
<td></td>
</tr>
<tr>
<td>Adjusted fruit intake</td>
<td>0.88</td>
<td>0.75</td>
<td>0.62</td>
<td>0.12</td>
<td>1.74</td>
<td>0.63</td>
<td>-4.27</td>
<td></td>
</tr>
<tr>
<td>Adjusted red meat and pork intake</td>
<td>0.89</td>
<td>0.61</td>
<td>0.32</td>
<td>0.11</td>
<td>0.19</td>
<td>0.98</td>
<td>-5.81</td>
<td></td>
</tr>
<tr>
<td>Vegetable intake</td>
<td>0.85</td>
<td>0.72</td>
<td>0.79</td>
<td>0.21</td>
<td>12.26</td>
<td>0.02</td>
<td>4.26</td>
<td></td>
</tr>
<tr>
<td>Adjusted candy intake</td>
<td>0.76</td>
<td>0.61</td>
<td>0.37</td>
<td>0.22</td>
<td>2.74</td>
<td>0.43</td>
<td>-3.27</td>
<td></td>
</tr>
<tr>
<td>Fish and lemon intake</td>
<td>0.80</td>
<td>0.82</td>
<td>0.72</td>
<td>0.16</td>
<td>9.31</td>
<td>0.03</td>
<td>3.31</td>
<td></td>
</tr>
<tr>
<td>High-salt snack food intake</td>
<td>0.80</td>
<td>0.66</td>
<td>0.55</td>
<td>0.21</td>
<td>2.63</td>
<td>0.45</td>
<td>-3.37</td>
<td></td>
</tr>
</tbody>
</table>

\(r_{(MZ)}\) Pearson’s correlation coefficient among monozygotic (identical) twin pairs for the given food-beverage category; \(r_{(DZ)}\), Pearson’s correlation coefficient among dizygotic twin pairs for the given food-beverage category; \(a^2\), percentage variance in the food-beverage category influenced by additive genetic influences (or, heritability); \(c^2\), percentage variance in the food-beverage category influenced by shared environmental influences; \(e^2\), percentage variance in the food-beverage category influenced by nonshared environmental influences; AIC, Akaike Information Criterion. MZ twin pairs, \(n = 102\); DZ twin pairs, \(n = 96\).

1 Intake of solid fruit minus the intake of fruit juice, punch, and soda.
2 Intake of beef, pork, and lamb minus the intake of chicken.
3 Intake of candy minus the intake of high-sugar foods.
In a follow-up investigation, de Castro (41) found that breakfast beverage intake was influenced by shared environmental influences in females but by genetic influences in males. A recent study of 5250 male and female twin pairs examined the heritability of breakfast consumption frequency among 16- y-old youth (42). The results indicated significant sex differences, and the authors concluded that “Breakfast eating is moderated differentially in adolescent boys and girls. Unlike boys, girls are much influenced by the family and pair-specific environment. In girls, environmental influences may override genetically driven factors” (p 512). The sex differences in the present study need replication. Future studies should also test for gene-environment correlations (43), ie, the extent to which boys and girls differentially place themselves in food environments that influence eating.

A third main finding was the consistent evidence of shared environmental influences on food-beverage intake phenotypes, especially for girls. Adult twin studies also reported evidence for shared environmental influences on eating phenotypes (18, 30), which supports the notion that the shared environment can influence short-term eating patterns. Specific aspects of the home environment were not measured in the present study, but merit further research. It is important to measure aspects of the shared and nonshared environments, respectively, to identify how specific life experiences affect food intake. Developmental behavior genetic studies used special questionnaires to identify aspects of the home environment that are associated with differences in sibling development (44, 45). Similar methods may be informative when studying the development of child eating patterns, although “shared” environmental measures can be genetically influenced (46).

BMI was highly heritable in both boys and girls, consistent with previous studies (47, 48). Moreover, BMI was modestly correlated with increased bread and butter intake in girls—an association that was better accounted for by a genetic correlation than by an environmental one. This finding shows a novel gene-behavior association, because the genes influencing greater body weight exert their influence, in part, through their effects on a specific dietary pattern. The specific genes influencing both phenotypes are unclear, and future research should devote greater attention to the role of genetic correlations involving adiposity and eating phenotypes in the development of child appetite. It should be noted that, by and large, the present study failed to detect associations between child weight status and 24-h food and beverage intake, which is consistent with previous research (49). Future studies in children may prosper by measuring broader eating patterns and styles and food-beverage choices over longer periods of time. Ascertainning a matrix of food intake phenotypes may enhance the discovery of genetic correlations between food intake and body fat in children. One phenotype showing promise in molecular genetic studies is dietary disinhibition (50), ie, the loss of self-imposed control of eating in response to external or emotional stimuli. Questionnaire (51) and laboratory protocols (52) that measure this trait in children may be informative for genetic studies (53).
The findings from this study should be interpreted in light of their limitations. First, the dietary recall procedures did not permit estimation of total and macronutrient intakes. The inheritance and environmental effects reported for specific foods and beverages may have resulted secondarily from their associations with total intakes that were the primary targets for inheritance and environmental effects. Second, the study did not measure children’s broader eating styles or patterns (eg, dietary restraint) or food and beverage intake over longer periods of times, such as weeks or months. There is evidence from adult twin studies that genetic and environmental influences on single-meal intake are not identical to those influencing 24-h food intake (14, 15). Third, the study examined only white families. Fourth, it is unclear to what extent the children’s intake of the specific foods and beverages in this study reflected their own preferences for those items rather than their mothers’ intentions to provide those items. Moreover, it is true that parents have different expectations for boys and girls, and there is a sex bias in how parents treat children (54). It is possible that some of the observed sex differences in this study related to the respondents’ differential expectations of boys and girls rather than to true sex differences in food and beverage intake per se. Future genetic studies should incorporate measures of parent feeding attitudes and practices. Fifth, because the food intakes were recorded for the same day for both members of each twin pair, shared environment effects were maximized. Foods provided by parents and schools may be very similar and the foods that were available for consumption likely would also be similar. The finding of relatively high shared environment effects may have been due to the fact that there was a high similarity in the foods available or provided. Finally, the heritability estimates for certain food-beverage categories should be given little if any weight, given the generally poor fit of even the best-fitting models.

An issue when interpreting the present findings is the “equal environments assumption,” that is, the extent to which greater similarity in dietary intake among identical than among fraternal twins is because the former group may be exposed to more similar environments. This issue has received limited investigation with respect to adult eating patterns (55, 56) but has not been studied in children. However, across a range of social, cognitive, and personality phenotypes investigated in the literature, heritability estimates for children appear to be influenced minimally if at all by violations of the equal environments assumption (26).

In summary, there were sizeable genetic influences on 24-h food and beverage intake in the 7-y-old children studied. The magnitude of genetic and home environmental influences differed by sex, which suggests sex differences in the development of eating patterns. The genes promoting greater relative body weight partially exert their influence by promoting increased bread and butter intake consumption in girls. Still, the general lack of association between the children’s BMI and intake of specific food-beverage categories suggests that a wider matrix of eating phenotypes should be studied. Disinhibited eating tendencies may warrant investigation in genetic studies of child energy intake and obesity.

The authors’ responsibilities were as follows—MSF: contributed to formulation of the research question and analyses, data analyses, and writing of the manuscript; SAR: contributed to data collection and writing of the manuscript; RPC: contributed to data collection, data analysis, and writing of the manuscript; and JKH: contributed to the overall design of the MacArthur Longitudinal Study of Twins, data collection, formulation of the research question and analyses, data analyses, and writing of the manuscript. None of the authors reported any conflicts of interest.

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