

# ASSOCIATIONS BETWEEN NUTRITION AND BEHAVIOR IN 5-YEAR-OLD CHILDREN

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**Key Words:** sucrose, child behavior, dietary intake, attentional performance, diet and behavior

Refined sugar (sucrose and other nutritive sweeteners) accounts for a significant proportion of the calories consumed by children.<sup>1</sup> Furthermore, there has been a steady rise in per capita consumption of sugar over the past 20 years.<sup>2</sup> Norms for the quantity and range of sugar consumption by children have not been clearly established, but it may be likely that some children consume exceptionally high amounts of sugar, given the tremendous variability of familial dietary habits. Despite the likelihood of high sugar consumption among children, there have been few investigations of the effects of sugar intake on psychological and developmental variables in young children. Dental and medical outcomes have been thoroughly investigated,<sup>2</sup> but the effects of differing dietary intakes of sugar (particularly sucrose) on the behavioral-psychological functioning of children have just begun to be investigated.

There is limited evidence that certain dietary elements can affect cognitive and behavioral functioning of special child populations (i.e., hyperactive children). There have been claims that the ingestion of artificial food colors and flavorings, other food additives and natural salicylates produces adverse reactions in some children.<sup>3,4</sup> While the claims are based in part on anecdotal reports, controlled studies have produced equivocal results.<sup>5-8</sup> One recent study has offered support under methodologically sound conditions. Swanson and Kinsbourne<sup>7</sup> admitted hyperactive children into the hospital so that an additive-free diet could be

administered in a controlled manner. They administered a food coloring challenge test that approximated actual daily amounts of food coloring consumed by some children. To circumvent problems inherent in behavior rating scales, Swanson and Kinsbourne used a paired-associate learning task as a measure of cognitive functioning. They found that the children were significantly and adversely affected after the food dye challenge in comparison to placebo challenge. This study represented a significant improvement over earlier work by other investigators and paralleled a trend toward more biologically oriented investigations via animal studies<sup>9,10</sup> and toward greater use of methodology from behavioral toxicology.<sup>11</sup>

The food additives hypothesis is a tenable one that warrants further investigation. However, food additives may not be the only substances in diet that have adverse effects on children. Evaluations of a food additive-free diet are confounded by concomitant reduction of other dietary components such as sugars. In a recent study, Prinz et al.<sup>12</sup> found a correlation between sucrose consumption and observed behavior in hyperactive and nonhyperactive 4- to 7-year-old children. Mothers kept 7-day food records of the children's dietary intake. At the end of the week, each child was videotaped while playing in a playroom. Trained observers who scored the videotapes were completely blind to the children's characteristics and dietary intake, and were not even aware that dietary data had been collected. Observer reliability was high (0.84 to 0.95 for occurrence-only reliability). In the hyperactive group ( $n = 28$ ), estimated sucrose consumption was positively and significantly correlated with observations of destructive-aggressive behavior and restlessness. In the nonhyperactive group ( $n = 26$ ), estimated sucrose consumption was positively and significantly correlated with amount of movement around the playroom.

Based on 7-day food records (without at-

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tempting to manipulate the children's food-intake habits), Prinz et al.<sup>12</sup> reported that 86 percent of the food entries classified as high-sucrose products would have been eliminated in a food additive-free diet, compared to 45 percent for other food entries in the dietary record. Conversely, of all the food entries that would have been excluded in a food additive-free diet, 25 percent were classified as high-sucrose products, whereas only 6 percent of additive-free entries were high-sucrose products. In other words, it is likely that a child placed on an additive-elimination diet in the natural setting would experience a significant reduction in sucrose intake. The Prinz et al. work served to identify a specific diet-behavior relationship for sucrose that can be studied further.<sup>12</sup>

A report by Langseth and Dowd<sup>13</sup> on glucose tolerance suggested a possible, but as yet unproven, mechanism for the behavioral effects of a high sucrose intake. Langseth and Dowd administered 5-hour glucose tolerance tests to 261 hyperactive children (ages 7 to 9) and found that 74 percent of the children had abnormal glucose tolerance curves. Half of the abnormal curves were low and flat, similar to that seen in individuals with hypoglycemia. According to Langseth and Dowd, hypoglycemia is associated with an increased production of epinephrine, which can in turn stimulate a nervous or restless reaction. It has been hypothesized that ingestion of large amounts of sugar over an extended period of time may be responsible for such a reaction. Caution is suggested, however, in the interpretation of Langseth and Dowd's findings. A control group of nonhyperactive children of the same age range and tested under the same conditions was not included in the study. There is some controversy regarding interpretation of the glucose tolerance test. Limited data are available on the norms for children.<sup>14-16</sup> Apparently, children have norms and variability patterns that differ from those of adults, which Langseth and Dowd did not acknowledge. The significance of a flat glucose tolerance curve is also subject to question.<sup>17</sup> Nevertheless, glucose and insulin regulation effects on behavior offer a researchable mechanism, particularly in view of animal work on conditioned hypoglycemia.<sup>18</sup>

## **Methodologic Approaches**

At least three methodologic approaches can be found in the research literature on diet-behavior effects in children. These approaches include treatment regimens, experimental designs involving challenge testing, and correlational-descriptive methods.

The treatment regimen approach focuses on a dietary intervention involving elimination of the identified component in the diet. This approach was commonly used in evaluating the effect of food colorings and additives on the functioning of hyperactive children and in this context even took on a name, the "Feingold diet."<sup>3,4</sup> With this method, baseline assessment is conducted for a set period of time (e.g., 1 or 2 weeks) to determine the child's level of functioning prior to elimination of the target dietary elements. Following baseline, the elimination diet is instituted for a long enough period to permit adequate assessment of the effects on behavior. In some cases, the intervention period is followed by a return to baseline conditions during which the target dietary elements are introduced again into the diet.

There are advantages to the treatment regimen approach. This method allows for evaluation in the naturalistic setting, which could include comprehensive assessment of behavior at school, at home and in the clinic. The dietary hypothesis can be tested in a manner that assesses overall clinical impact and significance. The opportunity to reverse conditions (i.e., return to a non-elimination diet) on repeated occasions allows an evaluation of the functional relationship between independent (dietary) and dependent (behavioral) variables.

There are also disadvantages to the treatment regimen approach. Given the tentative nature of current diet-behavior hypotheses (particularly for sucrose), use of a dietary intervention may preclude more efficacious treatment approaches. For example, hyperactive children can benefit from psychological interventions aimed at improving parent-child interactions, peer relations, and adjustment at school, and from stimulant medication for attentional performance.<sup>19</sup> Parents who are caught up in the enthusiasm for dietary intervention may overlook the other forms of inter-

vention to the detriment of the child. Another disadvantage of the treatment regimen approach is that it is difficult to keep the children, parents and teachers blind to the dietary conditions. Consequently, changes in behavioral functioning may be attributable to subtle environmental responses to knowledge of diet rather than to the diet itself. If a treatment regimen approach is used in the evaluation of the effects of sucrose intake, it is not clear whether all sucrose would need to be eliminated or whether high-sucrose/low-sucrose conditions would suffice. Furthermore, the dietary level of other sugars (i.e., monosaccharides and other disaccharides) may confound the results of a treatment regimen approach.

The second major methodological category is an experimental design with challenge testing. With the experimental-challenge approach, children receive a concentrated amount of the target substance in a controlled laboratory setting and then their functioning is observed during the few hours following ingestion. The design includes a placebo challenge for which the same procedures are followed, but the child receives a substance that is inert in terms of hypothesized behavioral effects. To maintain integrity of the experimental design, placebo and authentic challenge substances are disguised to appear the same to the child and the evaluators (i.e., double-blind conditions).

There are several advantages to the challenge-experimental method. Each child ingests a standardized amount of the target substance. Testing can be readily conducted under controlled and uniform conditions. Temporal patterns can be assessed, at least over a relatively brief period of time. Double-blind conditions can be maintained. The order of challenge tests can be counterbalanced, and challenge tests can even be repeated to evaluate the replicability of effects. A final advantage is that the within-subject orientation of this approach permits examination of effects for individual children in addition to group analysis.

Two potential problems with the experimental-challenge method are how much of the target substance to give to the child, and what should be the ingestion rate. Because it is not practical to have several challenge days for

each child corresponding to different "dosage" levels, the investigator is forced to choose an amount and run the risk of selecting too much or too little to produce hypothesized behavioral effects. Another issue is the role of dietary variables over longer periods of time than the few hours associated with challenge testing. Dietary patterns over time may potentially account for behavioral effects above and beyond those observed following ingestion of single substances. Recent attempts to evaluate the effects of sugar ingestion on behavior using experimental-challenge methodologies have demonstrated the utility of this approach.<sup>20-22</sup>

The third approach is the descriptive-correlational method which, in contrast to the other approaches, does not involve manipulation of dietary variables. The descriptive-correlational approach is primarily useful for evaluation of larger groups of children, assessment of broader and existing relationships between dietary intake and behavioral functioning in the naturalistic environment, and generation of hypotheses and parameters that can then be incorporated into experimental methodologies. The Prinz et al. study<sup>12</sup> is an example of the descriptive-correlational method and has served to set up the sucrose-behavior hypothesis for more precise experimental evaluation. However, there is another issue arising from a correlational approach that has not been addressed by experimental-challenge methods. Namely, the possible cumulative or longer-term effects of a particular diet may account for behavioral effects not detectable through single-substance challenge tests, but a correlational design may at least begin to address possible diet pattern effects.

One obvious flaw in the correlational approach is that one cannot deduce direction of causality from a single correlational coefficient or result. It is possible, however, to begin to rule out competing explanations for a given result by examining the contribution of potential "third" variables. The following preliminary study illustrates in an explicit fashion how it is possible to begin to address causal questions for diet-behavior associations, even when the basic methodology is a nonexperimental design.

## Preliminary Study

The preliminary analysis presented here was part of a larger investigation of the association between dietary intake and behavior in children, and was based on a subsample of the overall database.

*Method.* Families were selected from birth announcements in newspapers dated 4½ years prior to the testing date and cross-checked with telephone listings. Based on birth records, families were excluded if the parents were not married or if the mother was less than 20 years old at the time of birth. Families were contacted by mail for possible participation. All participating families received a \$20 stipend.

The subsample for this presentation included 91 Caucasian boys between the ages of 4 years, 6 months and 5 years, 6 months. Children with retardation, physical disability or pronounced medical problems were excluded from the sample. Families were predominantly from the middle class.

Mothers were taught to maintain a daily record of their children's food intake. A staff member visited the home and demonstrated the recording procedures. Mothers were instructed to record everything the child ate (including snacks, toppings, etc.); to note the amount eaten, not the serving portion; and to maintain the child's usual diet. Mothers were given a plastic ruler and a set of graduated measuring cups to improve accuracy of recording and an instruction booklet for reference during the week of dietary monitoring. Mothers recorded time of day, quantity of food eaten and a description of each food item for eight consecutive days. After the first day, a staff member reviewed the record with the parent to ensure thoroughness. For purposes of analysis, the first day's record was discarded, leaving a 7-day record.

Food records were coded based on the University of Massachusetts (Amherst) Nutrient Data Bank (MNDB).<sup>23</sup> For each food entry, the coder determined a food code, a portion code and a portion multiplier. The MNDB was particularly useful for this investigation, because the system has over 5,000 food entries, includes several "fast food" items, permits recipes to be represented and provides extensive data on sucrose content.

To assess reliability of food coding, a single day's record was sampled from each of 21 children's food records and then coded independently by two coders. The coders agreed on specific food codes for 96 percent of the food entries. Based on MNDB processing of nutrient content, intercoder reliability represented by Spearman correlation coefficients was found to be 0.90 for sucrose, 0.92 for total carbohydrate, 0.90 for fat and 0.86 for protein.

At the end of the week of food intake recording, each child was tested individually in a controlled setting. Because one of the central characteristics of childhood hyperactivity is difficulty sustaining attention, the chosen task involved assessment of attentional performance. The task was a modified version of the Continuous Performance Test (CPT) which has been used extensively with hyperactive children.<sup>24,25</sup> An Apple microcomputer controlled the presentation of slides showing pictures of animals in color. Each of 140 slides was presented for 500 msec with 2,300 msec between trials. Children were taught to press a response lever as soon as they recognized a picture of a duck (target stimulus) and to refrain from responding for all other animals. The target occurred on 42 trials and a false-alarm stimulus (an eagle) also occurred on 42 trials. D-prime, a measure of sensitivity derived from signal-detection theory, was computed from hit rate and false-alarm rate as an overall index of performance.

*Results and discussion.* The purpose of this preliminary study was to determine whether lower performance on the sustained attention task was associated with a high intake of sucrose. For each child, sucrose consumption was defined as mean daily sucrose intake in grams, based on analysis of the 7-day food record, divided by body weight in kilograms. The 91 boys were rank ordered with respect to sucrose consumption, in order to identify percentile cutoff scores for extreme groups. The high-sucrose group consisted of 23 boys at or above the 75th percentile who consumed a daily average of 6.65 g/kg sucrose (range: 5.47 to 9.55 g/kg). The low-sucrose group included 23 boys at or below the 25th percentile, who consumed a daily average of 2.56 g/kg sucrose (range: 0.56 to 3.23 g/kg).

If there is no validity to the contention that high sucrose intake affects child behavior, then what the children ate during the week should have no relationship to their attentional performance at the end of the week. To assess a sucrose-behavior association, the high- and low-sucrose groups were compared with respect to d-prime, hit rate and false-alarm rate using one-tailed t-tests. As shown in Table I, boys in the high-sucrose group scored significantly lower than the low sucrose group on d-prime sensitivity, indicating a poorer attentional performance. The high sucrose group had a significantly lower hit rate, but not a significantly higher false-alarm rate, suggesting that lower d-prime sensitivity was due primarily to missing the target stimuli instead of over-responding to nontarget stimuli.

On the basis of the group comparison alone, it is not possible to conclude with any degree of certainty that high sucrose intake had a direct effect on attentional performance. An alternative explanation is that some other third variable, such as socioeconomic status, had a causal effect on sucrose intake and attentional performance and thereby made it appear as though the two primary variables were related. In an attempt to address the "third variable"

**TABLE I**  
**Sustained Attention for Boys (Age 5)**  
**With High and Low Sucrose Intake**

Variable	High Sucrose (n = 23) Mean (SD)	Low Sucrose (n = 23) Mean (SD)	T	p
CPT D-Prime	2.78 (1.14)	3.28 (0.77)	1.75	0.04
CPT Hit Rate	0.87 (0.19)	0.95 (0.05)	2.05	0.02
CPT False Alarm Rate	0.13 (0.14)	0.11 (0.12)	0.41	NS

CPT: Modified version of the Continuous Performance Test

hypothesis, high- and low-sucrose groups were compared with respect to mother's and father's education (in years), total family income, occupational status of head of household, number of children in the family, child's body weight and child's IQ on an abbreviated version of the Wechsler Preschool and Primary Scale of Intelligence (WPPSI). As shown in Table II, six of the seven variables did not significantly discriminate between the two groups. The only variable which was close to

**TABLE II**  
**Comparison of High- and Low-Sucrose-Intake Groups**  
**With Respect to Potential "Third" Variables**

Variable	High Sucrose (n = 23) Mean (SD)	Low Sucrose (n = 23) Mean (SD)	T	p
Mother's education	14.9 (2.0)	15.5 (2.3)	0.88	NS
Father's education	15.3 (3.4)	16.7 (2.4)	1.59	0.06
Family income	\$38,424 (16,554)	\$34,511 (14,741)	0.85	NS
Occupational status	70.9 (15.9)	74.4 (13.0)	0.82	NS
Child's body weight (kg)	18.1 (2.0)	19.0 (1.9)	1.44	NS
No. of children in family	2.2 (0.7)	2.3 (0.9)	0.18	NS
Child's IQ (WPPSI)	116.7 (11.7)	116.0 (12.9)	0.19	NS
Mother's parenting (score on KBPAC test)	24.3 (7.5)	23.0 (5.6)	0.65	NS

WPPSI: Wechsler Preschool and Primary Scale of Intelligence

KBPAC: Knowledge of Behavioral Principles as Applied to Children

TABLE III

## Nutrient Intake for Boys with High and Low Sucrose Consumption

Variable	High Sucrose (n = 23) Mean (SD)	Low Sucrose (n = 23) Mean (SD)	T	p
Daily kilocalories (kcal/kg)	101.4(21.1)	83.6 (13.4)	3.40	0.001
Daily protein (g/kg)	3.03(.83)	3.16 (.73)	0.57	NS
Daily fat (g/kg)	3.73 (1.37)	3.26 (.89)	1.37	NS
Daily carbohydrate (g/kg)	13.1 (4.3)	10.1 (2.5)	2.96	0.005
Sucrose as percentage of total calories	26.4 (7.3)	11.8 (2.7)	8.98	0.0001

0.05 significance was father's education: fathers of boys in the high-sucrose group had an average of 1.4 years less education than the fathers of boys in the low-sucrose group, although both groups averaged at least 3 years of college education. Mother's education did not discriminate the groups. Furthermore, the groups were highly comparable with respect to family income, family size and child IQ. If a third variable did account for the observed relationship between sucrose intake and attentional performance, it was not apparent from the comparison of groups with respect to the potential third variables considered here.

Another issue that has been raised regarding correlations between sucrose intake and behavior is the direction of causality. It is plausible that children characterized by hyperactive and impulsive behavior might be more difficult to control with respect to dietary intake, and as a consequence consume more high-sucrose foods; that is, the behavioral variable might have caused the dietary variable, rather than the converse. To begin to address the issue of causal direction, an attempt was made to determine what accounted for differential sucrose intake for the two groups. Mothers were asked whether there were any household rules regarding their child's access to foods in the refrigerator and food cabinets, and then rated in terms of the degree of restrictiveness on a 4-point scale (0 = no rules or limits, 1 = few limits, 2 = moderate limits, 3 = highly restrictive limits). Mothers of high-sucrose con-

sumers were rated significantly less restrictive (mean 0.83, SD 0.98) than mothers of low-sucrose consumers (mean 1.83, SD 1.2;  $t[44] = 3.16$ ,  $p = 0.003$ ). The difference in sucrose intake between the two groups is attributable to differences in family rules regarding children's accessibility to food. If child sucrose intake is due to parent-determined eating patterns and rules, then the hypothesis that child hyperactivity causes higher sucrose intake is less tenable.

However, because mothers in the high-sucrose group were found to be less restrictive about food access, it was possible that they were also less effective in general parenting skills. To test this competing hypothesis, mothers were administered a 50-item test called "Knowledge of Behavioral Principles as Applied to Children" (KBPAC)<sup>26</sup> as an index of parental childrearing knowledge. The high- and low-sucrose groups did not differ significantly with respect to maternal scores on the KBPAC, and were comparable in terms of mean number of correctly answered items (see Table II).

High- and low-sucrose groups were compared with respect to intake of other nutrients. As shown in Table III, the groups did not differ significantly for protein and fat intake. As one might expect, the high-sucrose group consumed about 30 percent more carbohydrate than the low-sucrose group. The high-sucrose group had a significantly ( $p = 0.001$ ) higher intake of total calories. Finally, it was noted that

26.4 percent of the high-sucrose group's caloric intake was accounted for by sucrose compared with 11.8 percent for the low-sucrose group, a sizable difference.

**Conclusions.** The preliminary study presented in this paper suggests that there may be an association between diets characterized by a high sucrose component and reduced attentional performance in a normative sample of boys. Body weight was statistically controlled in the analysis. Variability due to age of child was minimized by focusing on a narrow age range (4.5 to 5.5 years). Dietary and attentional data were carefully and independently collected. Potential "third" variables, in particular socioeconomic status, child IQ and parental competence, were examined in order to begin to rule out alternative explanations for the observed association. It is reasonable to suggest from these preliminary data that the hypothesis of a longer-term (e.g., 1 week) effect from high sucrose ingestion is a viable one in need of further examination.

The precise and short-term methodology used in challenge studies of sucrose need not be abandoned. However, an accommodation needs to be made in the working model of diet-behavior phenomena that takes into account dietary intake effects which may have accrued over time. In psychology, there is a parallel issue surfacing in the area of applied behavior analysis. Operant behavior analysts have contributed a precise technology for the examination of functional relationships between specific behaviors and specific environmental events that occur just prior to (antecedents) and just after (consequents) the target behavior. Quite recently, Wahler and Fox<sup>27</sup> have begun to expand the conceptual framework of behavior analysis to allow for the inclusion of what they refer to as "setting events." Setting events are stimuli which might not occur in temporal proximity to the observed behavior but which nevertheless exert a controlling influence over that behavior. High sucrose intake over several days could potentially serve as a setting event which sets the occasion for later performance on attentional tasks. Models of diet-behavior effects in general may have to account for delayed as well as immediate effects.

## Summary

Caution is recommended in the interpretation of the reported findings. The magnitude of group differences for the attentional variables was not large, even though significant effects were obtained. It is not possible to generalize from these results about the likely detriment in attentional performance given a particular level of sucrose intake. Furthermore, the findings in this study need to be replicated by other investigators, and efforts should be made to determine the origin of this association between diet and behavior. □

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## DIET AND HYPERACTIVITY

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**Key Words:** ethanol, caffeine, sugar, aspartame, behavioral effects of dietary substances

The Child Psychiatry Branch of the National Institute of Mental Health (NIMH) has conducted a series of studies on the behavioral effects of some common dietary substances in children. This work grew out of previous studies of stimulant drug effects in hyperactive children and normal controls. A brief summary of the methodology that has been developed for these studies of ethanol, caffeine and sugar is presented here; these data have been reviewed in detail elsewhere.<sup>1</sup>

### **Ethanol**

In a recent study of the behavioral and physiological effects of a single dose of ethanol in a group of 22 grade school children, Behar et al. found that use of a similar intoxication by self-

report scale and memory task produced findings parallel to those found in adult populations.<sup>2</sup> Specifically, the subjective High Assessment rating<sup>3</sup> and the picture memory task of Parker et al.<sup>4</sup> both showed significant changes at 30 minutes, which were gone by 60 minutes. Objective and subjective behavioral changes were much less striking for the children than for the adults, and these effects were almost gone by 60 minutes. Furthermore, a standing steadiness task, extremely alcohol-sensitive for adults, was not significantly affected for the pediatric group. The pharmacokinetic data, however, suggest more rapid absorption and metabolic handling of alcohol in children. There may also be weaker subjective effects of alcohol for children, but the differences between age groups might be explained by blood alcohol concentration alone.

### **Caffeine**

An ongoing series of studies has examined the effects of caffeine in grade school children.<sup>5,6</sup> Single-dose studies compared the be-

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