

Sucrose and Delinquency: Behavioral Assessment

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ABSTRACT. In this study, a double-blind challenge design was used to evaluate the hypothesis that sucrose ingestion may compromise the behavioral performance of juvenile delinquents. Subjects were 58 white delinquents, 57 black delinquents, and 39 white nondelinquents. The behavioral assessment included tasks that are relevant to delinquency and that might be expected to be disrupted following sucrose ingestion. The results provide no evidence that sucrose ingestion impairs the performance of juvenile delinquents. In fact, the results of several analyses indicated that the sucrose breakfast was associated with improved performance. In additional analyses the effect of sucrose on particular subgroups of juvenile delinquents was evaluated. Statistical interactions indicated that the performance of delinquents rated as more behaviorally disturbed benefited from sucrose ingestion, whereas those delinquents with less pronounced behavior problems tended to show impaired performance following a sucrose-loaded breakfast. These results indicate that simple statements regarding the effects of sucrose ingestion on behavior are likely to be misleading and highlight the need to consider individual difference variables when investigating the effects of sucrose on juvenile delinquents. *Pediatrics* 1990;86:244-253; *behavior, delinquency, hyperactivity, neuropsychology, sucrose.*

ABBREVIATIONS. ANCOVA, analysis of covariance; CBC, Child Behavior Checklist; OSTT, Oral Sucrose Tolerance Test.

Sugar has received considerable attention from both lay and scientific communities as a substance

that may engender the behavior problems associated with criminality. Research in this area has been prompted, in large measure, by reports of the effects of sugar on the behavior of hyperactive children. Several investigators have reported that sugar ingestion is associated with signs and symptoms of hyperactivity,¹⁻³ but in the majority of controlled experiments, no evidence was obtained to indicate that sugar exacerbates the behavioral excesses of hyperactive children.⁴⁻⁶ Although sugar (sucrose) does not appear to induce excessive motor behavior per se, it is possible that sugar ingestion influences the psychological processes that underlie the impulsive, acting-out, and aggressive behaviors associated with juvenile delinquency and adult criminality.

Schoenthaler^{7,8} reported the initial correlational research that linked sugar with delinquency. He concluded that elimination of refined sugar from institutional diets reduced conduct problems within juvenile facilities. However, serious questions can be raised about the validity of Schoenthaler's conclusions because of methodological difficulties in his research design. Virkkunen and Huttunen⁹ studied sugar (glucose) metabolism of adult criminals. They reported that, compared with control subjects, habitually violent and recidivistic males with Antisocial Personality Disorder were more likely to have low levels of serum glucose during an oral glucose tolerance test,⁹ and that their nadir serum glucose levels took longer to return to baseline.¹⁰ In a subsequent article, Virkkunen¹¹ reported that offenders with a history of Unsocialized Aggressive Conduct Disorder exhibited enhanced insulin secretion after a glucose load.

Taken together, these results suggest that unusual glucose metabolism may be correlated with many of the behavioral disturbances associated with juvenile delinquency and adult criminality. There are, however, serious limitations to the re-

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search in this area. Apart from inadequate nutritional control and other methodological limitations, investigations with both juvenile delinquents and adult criminals have remained correlational, precluding conclusions about causality. Moreover, there have been no attempts to identify specific components of behavior that may be affected by sucrose.

An interdisciplinary investigation was therefore conducted to explore the biochemical and behavioral responses of juvenile delinquents to the ingestion of sucrose. This article is the initial report of the behavioral assessment phase of the experiment; oral sucrose tolerance test and nutritional status results were described by Gans et al.¹² The primary goal in this portion of our investigation was to determine whether consumption of a meal containing sucrose, as compared with aspartame, compromises the behavior of juvenile delinquents. Because it is unlikely that a sucrose challenge has equivalent behavioral sequelae in all delinquents, we were also interested in evaluating the responses of subgroups of persons who might be particularly prone to behavioral disruption following sucrose ingestion. A battery of psychological assessment tools and behavioral tasks relevant to delinquency was administered to explore the possible effects of a high sucrose meal. Although it was not possible in this study to resolve all methodological difficulties that typify diet and behavior research,^{4,6,13-15} we can, based on the results make some conclusions about the effect of sucrose ingestion on delinquents as well as highlight several important questions for future research.

METHOD

Subjects

The juvenile delinquent subjects were randomly selected from a group of volunteers, aged 14 to 19 years, who were incarcerated in a maximum security correctional facility for juvenile offenders. The majority of youths in this facility were reared in large urban communities, are recidivists, and/or have a history of violent behavior. To our knowledge, the youths who volunteered were a representative sample of the institutional population. Nondelinquent comparison subjects, 14 to 19 years of age, were recruited from four public high schools in a smaller urban community; with the exception of civic citations (eg, underage drinking), the nondelinquent sample had no history of police contact. Unfortunately, because of sociodemographic differences between communities of origin, it was not possible to obtain a control group that was matched in terms of all relevant variables. Nevertheless, inclusion of the nondelinquent comparison group

allowed us to assess the generality of any differences in behavior observed in the delinquent subjects.

Both the juvenile delinquent and nondelinquent subjects were male and were a subset of those who had completed the oral sucrose tolerance test (OSTT) protocol described by Gans et al.¹² The total sample for the behavioral challenge protocol consisted of 119 delinquents. Of these, 58 were white, 57 were black, and 4 were Hispanic or of mixed racial origin (the last group of subjects was too small to include in statistical analyses). The nondelinquent group consisted of 39 white male adolescents. For delinquents, attrition between the OSTT and challenge phase (18 subjects) was due primarily to release from the institution and security confinements; attrition in the comparison group (2 subjects) resulted from lack of interest.

Appropriate institutional review boards approved this project, and informed consent was obtained from all subjects and from the parents of subjects who were younger than 18 years of age at the time of recruitment.

Breakfast

The breakfasts consisted 84 g (3 oz) of cereal, 224 g (8 oz) of 2% milk, and 336 g (12 oz) of orange drink. Sucrose- and aspartame-sweetened cereals and drinks were manufactured to be indistinguishable in taste and appearance; the cereals were reshaped from the standard commercial product to avoid a behavioral response bias. The sucrose-loaded breakfast contained 78 g of sucrose but no aspartame; this amount of sucrose was nearly identical with that used in the OSTT (75 g). The aspartame-flavored breakfast contained <1 g of sucrose and approximately 400 mg of aspartame; for convenience, we will refer to this breakfast as the "no-sucrose" breakfast. Because of our intent to match the two breakfasts in sweetness and because of our commitment to using foods that were available commercially, the breakfasts differed necessarily in their carbohydrate, protein, fat, and energy contents. Specifically, the sucrose-loaded breakfast (636 kcal) contained 80% carbohydrate, 11% protein, and 9% fat; the no-sucrose breakfast (470 kcal) contained 62% carbohydrate, 21% protein, and 17% fat.

Assessment

The tasks described in this report were chosen because they were assumed to be sensitive indices of performance that would maximize the likelihood of detecting performance differences following the two breakfasts. As a group, these tasks have been used frequently in diet and behavior research and

were relatively easy for subjects to understand. With the exception of a continuous performance task (25 minutes), all of the tasks were brief (less than 5 minutes) in duration. The tasks included:

Finger-tapping. The standard neuropsychological administration procedures for finger-tapping were followed.¹⁸ Subjects were required to press a telegraph key as rapidly as possible for 10 seconds with the index finger of their dominant and nondominant hands. The dependent variable for each hand was the average of three trials that had a maximum range of five taps and that represented each subject's best performance.

Two-Minute Tap. As in previous research,¹⁹ subjects were required to press a telegraph key with the index finger of their dominant hand for 2 minutes. We included this variation of the more traditional finger-tapping measure to test the effects of substance on motor endurance and coordination throughout time. The dependent variable was the total number of taps.

Trailmaking. The trailmaking test²⁰ was used to measure planning and motor speed. The total time necessary to complete the trail and the number of errors were the dependent measures for both trails A and B.

Digit Span. The Wechsler Adult Intelligence Scale-Revised Digits Forward and Digits Backward subtests were used to assess short-term memory. The total score from the Wechsler Adult Intelligence Scale-Revised scoring procedure was used as the dependent variable for each subtest.

Continuous Performance Test. This computerized version of the Continuous Performance Test was modeled after one used in Connors' research with hyperactive children (Keith Connors, oral communication, 1985). Subjects were required to press a button as quickly as possible whenever they saw the same letter flash twice in a row. The 800-trial task was 25 minutes in duration. Misses and false alarms were the measures used in analyses.

Experimenter Ratings. At the completion of each day of testing, the experimenters used a three-point scale to rate subjects on 32 adjectives that reflected mood and behavior (eg, irritable, fidgety). This rating scale has been used with hyperactive children.²¹ The dependent variable was the total number of points accrued.

Descriptive Measures. Measures of cognitive functioning and behavioral disturbance were included to allow for a more detailed assessment and interpretation of the relations between juvenile delinquency and response to the two breakfasts. These included:

Intelligence. An estimate of intelligence was obtained using the Peabody Picture Vocabulary Test-Revised, Form L.

Rating Scales. Two behavior checklists were used to assess the problem behaviors of the delinquent subjects. For delinquent subjects, the Child Behavior Checklist (CBC)²³ was completed by a teacher and the Revised Behavior Problem Checklist²⁴ was completed by a cottage counselor. In addition, an attempt was made to have one parent of each nondelinquent subject complete the latter checklist.

The design and assessment protocol used in this investigation were more extensive than the description given in this article. The article describes a between-subjects design whereas the actual design was a double-blind crossover challenge. In other words, each subject received both the sucrose and no-sucrose breakfasts during 2 days of behavioral assessment to evaluate within-subject (intrasubject) substance effects. The tasks included in this article were used to assess these effects and, therefore, were administered to subjects on both occasions.

We describe data from the first day of testing only because preliminary analyses revealed significant "practice effects" of a complex nature: Whereas subjects typically improved with tasks involving skill or strategic components, their performance on the second day of testing tended to be poorer with tasks requiring persistence despite boredom and fatigue. Interpretation of data from crossover designs is exceedingly complex and is even more hazardous when the experiment involves multiple dependent measures and practice effects.^{16,17} In light of these factors, we considered it prudent to omit the data from the second day of testing in this initial presentation of our results.

The results from assessment techniques not described in this article will be described in subsequent articles. These were administered on only one day of testing and included traditional measures of learning and memory, tasks developed in our laboratory to investigate the psychological processes underlying behavioral disinhibition, subjective estimates of mood, psychophysiological assessment, self-report inventories, diagnostic assessment, and institutional file reviews. To date, only data from behavioral measures have been analyzed. The results for these additional measures were more difficult to interpret than the results described here. These tasks assessed diverse constructs and, perhaps as a consequence, were not uniformly influenced by the substance manipulation. Nevertheless, the results in some important ways parallel those described in this article.

Procedure

Counterbalancing. Subjects were randomly assigned to receive either the sucrose or no-sucrose

breakfast (see "Assessment"). In addition, subjects were consecutively assigned to receive one of the two orders of task administration. Order of task administration was counterbalanced to assess and control for the effects of substance throughout time. "Order 2" was the reverse sequence of tasks used in "Order 1."

Overview of Assessment. Two subjects were assessed simultaneously and were tested individually by one of three female experimenters. For delinquents, testing was conducted in one large room, whereas nondelinquents were tested in adjacent laboratory rooms. Subjects were separated visually but were within muted hearing distance of each other in both testing environments. Subjects were brought to their testing sites after an overnight (9 hour) fast. They were given breakfast and then completed either intellectual and diagnostic assessments or personality questionnaires. Behavioral assessments began 40 minutes after completion of breakfast and continued for approximately 3 hours, with the exception of a 15-minute rest period at the midpoint of each task protocol.

RESULTS

Analytic Strategy

In this initial report, our principle concerns were to detect any possible effects of sucrose ingestion and to minimize spurious findings that might result from the use of a multiple *t* test strategy. To further minimize the potential for type I (false positive) errors, only the primary dependent variables for each task were included in the analyses, ie, those variables defined in the task descriptions. In addition, the Geisser-Greenhouse probability value²⁵ was used as a correction for the number of dependent variables.

Analyses were conducted separately for each of the three subject groups. This strategy avoided the contributions to variance from race and delinquency status, but provided the opportunity to examine whether a similar pattern of substance response existed across the subject groups. Dependent variables were converted to *z* scores within each subject group so that each variable had an equal chance of contributing to the overall significance level. To simplify interpretation of the analyses, the *z* scores were computed so that higher scores were always associated with better performance. Intelligence (Peabody Picture Vocabulary Test-Revised) was used as a covariate in all of the analyses. In addition, adolescents scoring less than 65 on the Peabody Picture Vocabulary Test-Revised were excluded from analyses; although this cutpoint is low, the verbal intelligence of subjects within the lower

range of intellectual ability has been reportedly underestimated by the Peabody Picture Vocabulary Test-Revised.²⁶ This cutpoint removed 12 black delinquent subjects from the analyses, but did not affect the white delinquent and nondelinquent sample sizes.

Identical analyses were conducted within each subject group using repeated measures analyses of covariance (ANCOVAs). Whenever possible, four analyses were conducted within each subject group. The first and principle analyses were the substance-effect comparisons; these permitted assessment of whether performance following the sucrose breakfast was different from performance following the no-sucrose breakfast. Two additional analyses were conducted to investigate performance following the sucrose and no-sucrose breakfasts in subgroups of delinquents. In particular, we divided subjects into groups according to whether they obtained scores above or below the median on the CBC Hyperactivity and the Revised Behavior Problem Checklist Conduct Disorder dimensions were chosen to group subjects because of their relevance to the acting-out behaviors associated with delinquency. Within each subject group, we used Experimenter Ratings as a final analysis of whether observable mood and behavior differed after the sucrose and no-sucrose breakfasts.

We wish to note that subjects with low serum glucose levels performed no worse following the sucrose breakfast than following the no-sucrose breakfast. In fact, the means were in the opposite direction. Analyses that provide increased power may determine that this biochemical variable interacts with substance to influence performance.

The order of task administration was used as a factor in the simple substance effects analyses but order could not be used as a factor in either of the subgroup analyses because the resulting cell sizes were too small. Discrepancies between the degrees of freedom and subject sample sizes among the analyses were due to missing or incomplete data (eg, computer failure or missing teacher or cottage counselor ratings).

For purposes of brevity and clarity, only those *F* ratios achieving statistical significance and statistical trends that may affect interpretation of the sucrose and delinquency hypothesis will be reported. Furthermore, statistically significant findings without direct relevance to the sucrose and delinquency hypothesis will not be discussed.

Group Characteristics

Our inability to obtain parent education levels for most of the delinquent subjects prevented iden-

tification of subjects' socioeconomic status using the method recommended by Hollingshead (unpublished manuscript, 1957). Therefore, parent occupational levels alone were used to assign subjects to five classes of socioeconomic status. In the Table the median age, socioeconomic status, and Peabody Picture Vocabulary Test-Revised scores for the three subject groups are shown. As can be seen, these groups were different with respect to socioeconomic status and intelligence. In effect, the decision to analyze the data from each group separately, and then to examine whether a similar pattern of results was obtained across the three groups is supported by the socioeconomic status and Peabody Picture Vocabulary Test-Revised group differences.

Performance Analyses

White Delinquents. An ANCOVA was conducted with Substance and Order as between-subjects factors and the 11 performance measures as a within-subjects factors. Intelligence was used as a covariate. A significant main effect for substance was shown by these results, $F(1, 48) = 4.63, P < .05$ (Fig 1). The direction of this substance effect indicated that white delinquent subjects performed better following the sucrose breakfast than they did following the no-sucrose breakfast. Although the magnitude of this performance benefit varies somewhat across tasks, substance did not interact significantly with the dependent variables.

When CBC hyperactivity was included as a factor, the main effect for substance seen previously was no longer significant. Rather, there was a significant substance \times hyperactivity interaction, $F(1, 41) = 9.36, P < .01$ (Fig 2). Within the group of white delinquents identified as hyperactive, subjects receiving the sucrose breakfast actually outperformed subjects who received the no-sucrose breakfast. The opposite relation appeared to be true of the nonhyperactive subjects: their performance was better following the no-sucrose breakfast than it was following the sucrose breakfast, although the magnitude of performances differences between the two breakfasts was not as great as it was in the

hyperactive group. Thus, within a delinquent sample, there was no evidence to suggest that subjects who had been identified by their teachers as being relatively hyperactive were adversely affected by sucrose.

Using the Revised Behavior Problem Checklist Conduct Disorder dimension to group subjects, we again found a main effect for substance ($F[1, 39] = 4.77, P < .05$), but the substance \times conduct disorder interaction was not significant. Finally, experimenter ratings of mood and behavior did not interact statistically with substance.

Black Delinquents. As with white delinquents, data for the black delinquents were analyzed using an ANCOVA. There were no significant main effects for substance, indicating that performance following the sucrose breakfast did not differ from performance following the no-sucrose breakfast.

When CBC hyperactivity was added as a factor, a significant substance \times CBC hyperactivity interaction, $F(1, 29) = 6.63, P < .025$ was seen in the ANCOVA results (Fig 3). This interaction is very similar to that seen with the white delinquents: the hyperactive delinquents who had eaten a sucrose breakfast outperformed similar subjects who had received the no-sucrose breakfast, whereas nonhyperactive subjects performed better following a no-sucrose breakfast.

An ANCOVA using the Revised Behavior Problem Checklist Conduct Disorder scale provided no evidence that the conduct disorder measure was related to task performance, and experimenter ratings of mood and behavior were not differentially associated with the sucrose and no-sucrose breakfasts.

Nondelinquents. As with the white and black delinquents, the data for nondelinquents were analyzed using an ANCOVA. In this case, the ANCOVA yielded a significant substance \times order interaction, $F(1, 31) = 4.39, P < .05$. The interaction was due primarily to the performance of subjects receiving the no-sucrose breakfast: subjects receiving order 1 outperformed those tested using order 2 on the tasks administered both early and late in testing. The tasks administered in the middle of testing (Digit Span and Continuous Performance

TABLE. Mean Age, Socioeconomic Status, and Peabody Picture Vocabulary Test Scores for Delinquent and Nondelinquent Adolescents

	Delinquents		Nondelinquents (n = 39)
	White (n = 58)	Black (n = 57)	
Age (y)	16.72	16.50	16.64
Socioeconomic status	4.02	4.60	2.92
Revised Peabody Picture Vocabulary Test scores	89.77	78.33	110.92

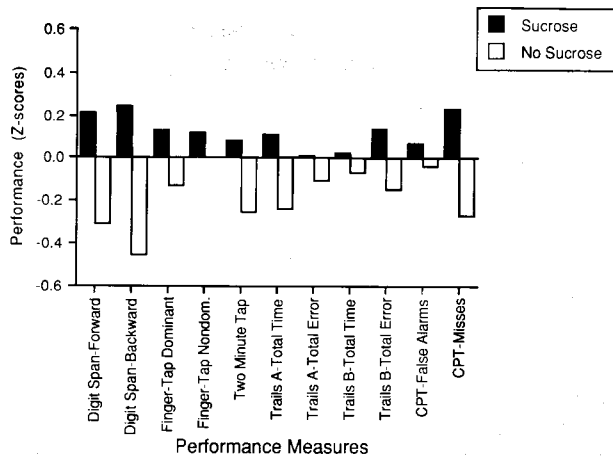


Fig 1. Substance effect for white delinquent subjects receiving sucrose and no-sucrose breakfasts, averaged across order of task administration.

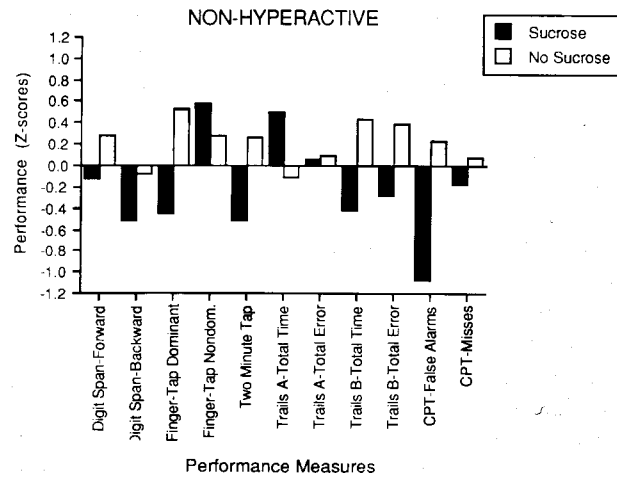
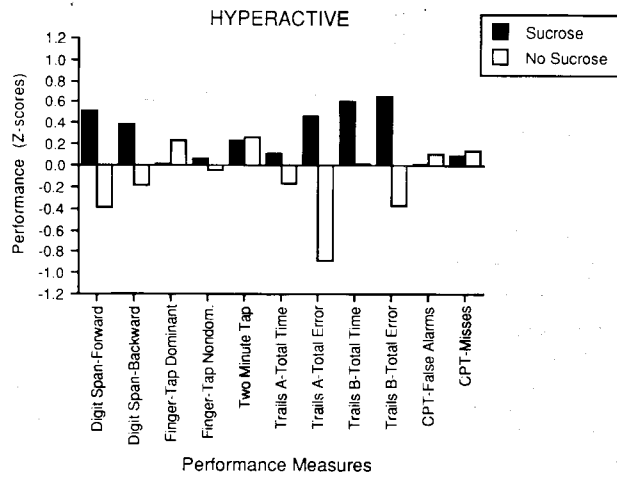


Fig 3. Substance \times Child Behavior Checklist hyperactivity interaction for black delinquents receiving sucrose or no-sucrose breakfasts.

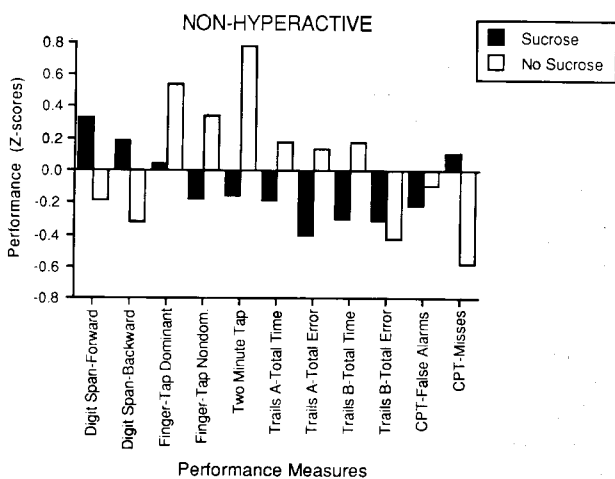
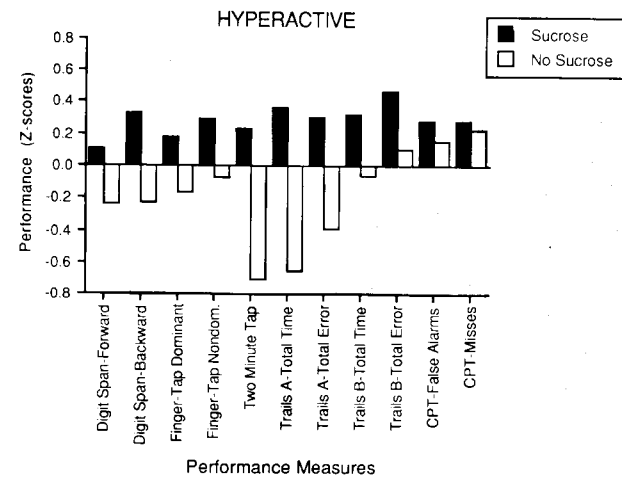


Fig 2. Substance \times Child Behavior Checklist hyperactivity interaction for white delinquents receiving sucrose or no-sucrose breakfasts.

Test) were not consistently related to order of task administration. That time of testing was not related to task performance in a linear fashion suggests that this interaction was due to the particular sequence of task administration rather than to substance-time course effects.

In the analysis of experimenter ratings, a statistical trend toward a substance \times rating interaction ($F [1, 35] = 3.27, P < .10$) indicated that experimenters tended to rate subjects as exhibiting better behavior following sucrose compared with the no-sucrose breakfast.

DISCUSSION

The purpose of this study was to test the hypothesis that sucrose ingestion has an adverse impact on the behavior of juvenile delinquents. Stated succinctly, there was no evidence of a negative effect of sucrose ingestion on performance. The overall pattern of results, across three subject samples and

numerous behavioral domains (see Assessment), provided no support for the contention that sucrose ingestion compromises behavior. Moreover, when there was a significant main effect for type of breakfast, as in the analyses involving the performance of white delinquents on the primary tasks, the sucrose breakfast was associated with improved, rather than impaired, performance. Because a substantial body of research attests to the heterogeneity of juvenile delinquents, we conducted additional analyses to determine whether sucrose consumption is associated with impaired performance in relevant subgroups of delinquent subjects. Analysis of task performance did, in fact, indicate that those delinquents rated as hyperactive on the Achenbach CBC responded differently to the breakfast manipulation than did nonhyperactive subjects. Contrary to popular lore, those delinquents described by their teachers as the most disruptive and behaviorally disturbed demonstrated better performance after the sucrose than after the no-sucrose breakfast. Although the differences in performance following the two breakfasts were less dramatic, delinquents receiving low CBC Hyperactivity scores performed somewhat better following the no-sucrose breakfast. This same interaction was observed in both white and black delinquent subjects.

The aforementioned results were obtained on tasks that were easily understood by subjects, required concentrated effort, and were assumed to be sensitive indices of performance (Digits Forward and Backward, Finger Tapping, Two Minute Tap, Continuous Performance Test, and Trails); with the exception of the Continuous Performance Test, they were brief in duration. Therefore, sucrose ingestion appeared to boost performance in tasks with both short-term (eg, Digits Forward) and sustained (ie, Continuous Performance Task) attention demands. These results were especially apparent among those subjects receiving high scores on the CBC Hyperactivity scale.

As noted earlier, our inability to obtain a sample of nondelinquents that resembled the delinquents in race, socioeconomic status, and intelligence restricted the usefulness of this comparison group. Nevertheless, the results for this group of age- and sex-matched adolescents are informative because they provide evidence that the generality of our findings with delinquents may be limited. In contrast to the analyses involving white delinquents, those for nondelinquents revealed no main effect for type of breakfast and, furthermore, indicated that substance interacted with the order in which the tasks were administered. Although these results appear to indicate that delinquents and nondelinquents respond differently to sucrose and no-su-

crose breakfasts, such a conclusion would be premature in the absence of research using a more adequately matched control group. It is possible that identical patterns of results would have been obtained in nondelinquent adolescents with sociodemographic backgrounds more similar to the delinquents used in this study.

In addition to demonstrating that ingestion of sucrose does not impair the performance of juvenile delinquents, the results of this study indicate that simple statements regarding the effects of sucrose ingestion on behavior are likely to be misleading. Although performance was found to vary depending on the presence or absence of sucrose in the breakfast, these effects were also dependent on the type of subjects employed and the sequence of task administration. The most consistent finding to emerge from these analyses was that delinquents with higher CBC Hyperactivity scores displayed better performance following a sucrose-loaded breakfast, whereas less disturbed subjects tended to demonstrate poorer performance following the sucrose breakfast. Thus, one effect of a sucrose-loaded breakfast may be to improve the performance of those delinquents with relatively poor daily functioning and to impair the performance of delinquents rated as having more appropriate daily behavior.

In interpreting the CBC hyperactivity \times substance interaction, it is important to remember that performance following one breakfast is relative to performance following the other. Thus, the performance-enhancing effects of the sucrose breakfast may also be interpreted as a detrimental effect of the no-sucrose breakfast. It is possible that the no-sucrose breakfast resulted in poorer task performance because, unlike the sucrose-loaded breakfast, it did not provide subjects with a readily available source of energy (ie, glucose). Thus, the significant CBC hyperactivity \times substance interaction might indicate that those subjects identified by their teachers as the most disruptive and hyperactive on the basis of classroom behavior are less able to compensate when physiological and environmental conditions are less than optimal. In contrast to the hyperactive delinquents, who performed very poorly after the no-sucrose breakfast, those subjects with more adequate behavioral controls may be capable of mobilizing psychological and physiological resources that compensate for a meal with less readily available energy. Although speculative, this interpretation is consistent with a large psychological literature indicating that children with behavior problems (ie, hyperactivity and conduct disorder) often display performance deficits that are attributed to suboptimal levels of arousal and that such deficits may be remedied by experimental and

pharmacological manipulations designed to increase level of arousal.²⁷

It should be noted that the concept of arousal has been criticized because divergent measures of arousal do not always agree. Such findings suggest that arousal is not a unitary phenomenon but a multidetermined construct. Regardless, diverse "arousal manipulations" have been found to reduce performance deficits in a variety of populations characterized by poor behavioral controls.

In addition to differences in amount of sucrose, the no-sucrose breakfast contained fewer kilocalories (166) and a different percentage of carbohydrate (62%) than the sucrose (80%) breakfast. Thus, it is possible that these differences contributed to the better performance of hyperactive delinquents following the sucrose breakfast. However, the fact that their enhanced performance after the sucrose breakfast was apparent early as well as late in testing indicates that any energy-related effects on performance probably involved a rapidly available source of energy. This pattern of results suggests that sucrose, rather than number of kilocalories per se, was the primary factor mediating the performance differences associated with type of breakfast.

The results of this study are not easily placed into a larger empirical framework because similar design strategies have not been used with delinquent subject samples. However, the present results do not support Schoenthaler's claim (eg^{7,8}) that refined sugar consumption is responsible for conduct disturbance, with the caveat that we did not assess behavioral responses to the sucrose and no-sucrose breakfasts outside of a laboratory setting. This limitation notwithstanding, there was no evidence that sucrose ingestion disrupted the behavior of delinquents with the context of a rigorous behavioral assessment (see Assessments). Furthermore, experimenter ratings of the behavior and mood of delinquent subjects did not differ following the sucrose and no-sucrose breakfasts; for the nondelinquents, ratings following the sucrose breakfast indicated that behavior and mood were somewhat better than after the no-sucrose breakfast.

Hyperactive children are at risk for juvenile delinquency^{28,29} and, like delinquents, are commonly thought to respond adversely to a sugar load. However, the present results support, in many ways, the conclusions of investigators who have reviewed the relations between sugar consumption and hyperactivity⁴⁻⁶: we failed to find a direct correspondance between sucrose ingestion and impaired performance. Furthermore, improved performance similar to that described in this article has also been observed in hyperactive children.⁵

There is sparse evidence, then, that an adverse reaction to sucrose underlies the attentional problems and poorly controlled behavior of children with symptoms of hyperactivity and/or conduct disorder.

The conclusions that have been drawn from the present results are qualified in several respects: our concerns center around the issues of analytic strategy, statistical power, and diet-behavior methodology. In a strict sense, the number of comparisons conducted with these data is problematic because some comparisons may be expected to be statistically significant by chance. However, the apparent complexity of sucrose and behavior relations necessitates the use of multiple comparisons. Furthermore, conducting a large number of comparisons provided a strong test of the hypothesis that sucrose ingestion impairs the performance of juvenile delinquents. It is noteworthy that, despite this strong test—and similar to the results of the majority of sucrose and hyperactivity investigations—there was no evidence to indicate that sucrose ingestion has a deleterious effect on performance.

A related issue is that of statistical power. Whereas the number of subjects tested was quite adequate for determining whether sucrose ingestion compromises the laboratory behavior of juvenile delinquents, there was a substantial loss of statistical power when the subjects were divided into subgroups (ie, CBC Hyperactivity and Revised Behavior Problem Checklist Conduct Disorder). Thus, in contrast to our conclusion regarding the absence of a simple, adverse effect of sucrose on behavior, we must be tentative in our interpretation of those findings involving the subgroup analyses. Nevertheless, several of these findings were intriguing and merit further investigation with a larger group of subjects. In the interim, we advocate extreme caution with respect to their clinical interpretation.

Several authors^{4,6,13-15} have specified important design issues that need to be considered in diet and behavior methodology. In accordance with these recommendations, an additional comparison substance should be included in future studies assessing the effects of sucrose on behavior. Although it is quite unlikely that the dose of aspartame used in this study can produce behavioral change,⁴ it has been suggested that aspartame may, under some conditions, produce adverse behavioral effects.³⁰ An additional control substance is necessary to evaluate this possibility. Furthermore, the use of aspartame as a control substance for sweetness created breakfasts that were unmatched in other respects. The use of a control substance equivalent in energy content to sucrose would provide a better assessment of the extent to which sucrose, as opposed to

energy intake per se, it responsible for differences in performance.

It has been argued that the ratio of dietary carbohydrate to protein may be more important than the absolute amount of sucrose in producing changes in behavior: as this ratio increases, the more likely subjects are to report drowsiness and display performance decrements.⁶ In the present study, the carbohydrate to protein ratio of the sucrose breakfast was more than twice that of the no-sucrose breakfast. The simple substance effects observed, however, were opposite in direction to those predicted from the larger carbohydrate to protein ratio of the sucrose breakfast in that the larger ratio was associated with performance improvement rather than performance decrement. Finally, more attention should be given to testing the hypothesized psychological and biochemical mechanisms underlying substance and behavior relations. To date, elevations in brain tryptophan and associated increments in serotonin synthesis are assumed, on the basis of results from animal studies, to be a plausible mechanism by which carbohydrate intake ultimately affects behavior.^{6,31-33} It is important to note, however, that there is controversy about this proposed mechanism.³⁴⁻³⁶

In summary, after comparing performance following a sucrose breakfast with that following a no-sucrose breakfast across two delinquent samples and one nondelinquent sample, the most parsimonious conclusion is that sucrose does not compromise delinquent performance. Furthermore, the results illustrate that attention to individual difference variables, such as the extent to which symptoms associated with hyperactivity are present, may be essential to a complete understanding of the relationship between sucrose and behavior.

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