



## EFFECTS OF SUCROSE INGESTION ON JUVENILE OFFENDERS WITH LOW, BORDERLINE, AND NORMAL NADIR SERUM GLUCOSE VALUES

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**Summary**—The effects of sucrose on the neuropsychological test performance of juvenile offenders with low (< 50 mg/dl), borderline (50–60 mg/dl), and normal (> 60 mg/dl) serum glucose nadirs during an oral sucrose tolerance test were examined using a double-blind crossover challenge design. Subjects ingested a sucrose-loaded (78 g) and a no-sucrose (< 1 g) breakfast prior to behavioral assessments. Offenders with atypically low glucose nadirs performed better after ingesting the sucrose-loaded breakfast than after the control meal. A similar effect was observed in offenders with serum glucose nadirs falling in the normal range whereas subjects with borderline nadirs performed comparatively poorly following both breakfasts. These results indicate that the relations among short-term sucrose consumption, biochemistry, and behavior are complex and highlight the need to rigorously test presumptions regarding the effects of sucrose on the behavior of juvenile criminal offenders.

### INTRODUCTION

The putative associations between sugar consumption and behavior problems have received considerable attention for more than a decade. Several research strategies have been employed to examine the hypothesis that refined sugar can impair the behavior and performance of hyperactive children, children described as 'sugar reactive', and juvenile offenders. For example, some studies examined whether long-term dietary sugar ingestion was correlated with behavior problems. The results of some correlational investigations did indicate that long-term dietary sucrose ingestion is linked to behavior problems (Kreusi, Rapoport, Cummings, Berg, Ismond, Flament, Yarrow & Zahn-Waxler, 1987, Prinz, Roberts & Hantman, 1980), although results from other correlational studies failed to find evidence for associations between long-term consumption and behaviors such as excess motor activity and inattention (Wolraich, Stumbo, Milich, Chenard & Schultz, 1986).

Hypotheses about a causal relationship between sucrose ingestion and behavior have typically not been confirmed when controlled methodologies are used. As examples, some challenge studies have examined the effects of sucrose on the behavior of children identified by parents and teachers as being 'sugar reactive' (e.g. Behar, Rapoport, Adams, Berg & Cornblath, 1984) while others have used 'hyperactive' children as Ss [i.e. Attention Deficit Hyperactivity Disorder (e.g. Milich & Pelham, 1986, Wender & Solanto, 1991, Wolraich, Milich, Stumbo & Schultz, 1985)]. With neither type of S sample have there been consistent or convincing demonstrations that acute sucrose administration produces adverse behavioral reactions such as motor, attention, and memory functions. In fact, acute sucrose administration is as often associated with performance enhancement as it is with performance decrements in school-aged children. The results of two additional challenge investigations indicate that preschool children, unselected for either sugar 'reactivity' or hyperactivity, may be adversely affected by sucrose ingestion. Rosen, Booth, Sorrell, McGrath, Bender and Drabman (1984) reported that young girls had poorer cognitive performance and displayed 'hyperactive' behavior following a high dose of sucrose, and Goldman, Lerman, Contois and Udall (1986) observed impaired sustained attention and inappropriate free play after a high sucrose dose.

Most challenge investigations have examined the short-term consequences of sucrose ingestion,

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leaving open the possibility that any negative effects of sucrose ingestion are the product of relatively long-term consumption patterns. The results of one recent study designed to assess this possibility demonstrated that daily ingestion of a moderate level of sucrose for a 3-week period was not associated with performance or behavior change in either a normal preschool sample or in a school age sample of children identified by parents as being 'sugar sensitive' (Wolraich, Lindgren, Stumbo, Stegink, Appelbaum & Kiritsy, 1994). If anything, the results indicated that, in comparison to aspartame and saccharin sweetened meals, sucrose ingestion might give rise to a calming impact on behavior. Together, challenge investigations have provided little, mixed, or no evidence to support the notion that either short- or long-term sucrose ingestion exacerbates problem behavior or disrupts the performance of children (for reviews, see Gray, 1987; Harper & Gans, 1986; Kreusi & Rapoport, 1986; Milich, Wolraich & Lindgren, 1986; Spring, Chiodo & Bowen, 1987; Wender & Solanto, 1991; cf. Schoenthaler, 1985, 1991).

These conclusions, as well as those to be made in subsequent portions of this paper, are tempered by considering that atypical patterns of sucrose ingestion may be an index of more comprehensive nutritional deficiencies. In turn, these deficiencies may be related to suboptimal intellectual and behavioral performance. In this framework, it is not the specific amount or pattern of sucrose consumed, but the overall pattern of dietary composition that becomes central to explanations of diet-related behavioral deficiencies. One method of testing this hypothesis involves assessing performance subsequent to periods of vitamin and mineral supplementation. Although some researchers have reported that supplementation has no impact on the intellectual performance of school-aged children (Nelson, Naismith, Burley, Gatenby & Geddes, 1990), the contrasting results and conclusions offered by Schoenthaler and his colleagues (Schoenthaler, Amos, Doraz, Kelly & Wakefield, 1991; Schoenthaler, Amos, Eysenck, Peritz & Yudkin, 1991) underscore the complexity of this issue. The potential for acute sucrose intake and for sustained, excessive sucrose consumption to interact with nutritional deficiencies to influence performance is an important hypothesis that should be tested further through controlled investigations.

In addition to focusing on the effects of sucrose on children, conjectures about sucrose ingestion have also centred on its potential for contributing to the disinhibited behavior of adolescent and adult criminal offenders. Research using the oral glucose tolerance test (OGTT) has provided evidence of anomalous glucose metabolism in adult offenders (Virkkunen, 1987) and subjective indications of hypoglycemia in adolescent offenders (Schauss, 1981; Schoenthaler, 1983; Schoenthaler, 1986). These results have been used to propose that sucrose consumption contributes to the expression of antisocial behavior and that restricting the sucrose intake of criminal offenders will be therapeutic [although more recent interpretations of these findings have stressed the role of overall nutritional status rather than the contributions of any one dietary component such as sucrose (Schoenthaler, 1991)]. Unfortunately, previous investigations have not examined whether the short-term performance and behavior of criminal offenders with anomalous OGTT responses is actually impaired by an acute dose of sucrose. That is, these early studies did find evidence that adolescent and criminal offenders have atypical biochemical responses to sucrose ingestion, but the behavior of these Ss was not examined in the hours immediately following sucrose intake.

We administered an oral sucrose tolerance test (OSTT) to juvenile offenders and control Ss as part of a study that assessed the short-term effects of sucrose consumption on performance (Bachorowski, Newman, Nichols, Gans, Harper & Taylor, 1990; Gans, Harper, Bachorowski, Newman, Taylor & McDonald, 1990). Using a cutpoint comparable to that used by Virkkunen & Huttunen (1982) and typical of the cutpoints used for diagnostic purposes (Messer, Morris & Gross, 1990), *viz.* 50 mg/dl, we observed that more offenders than controls displayed atypically low serum glucose nadirs (Gans *et al.*, 1990). Specifically, 29% of the offenders but only 7% of the nonoffenders exhibited nadirs below 50 mg/d (2.8 mmol/l) at some time during the postprandial portion of the OSTT. For comparison, less than 15% of normal adult samples are thought to experience nadirs in this range (Lev-Ran & Anderson, 1981). Despite the highly significant difference between offenders and nonoffenders in serum glucose nadirs, it is important to emphasize that there were no group differences in the signs and symptoms required for a diagnosis of reactive hypoglycemia (Berkow & Fletcher, 1987; Sherwin & Felig, 1981). In fact, none of the Ss met the full clinical criteria for this disorder. These results, then, supported the hypothesis that a substantial proportion of juvenile offenders have abnormal glucose metabolism but

failed to uphold contentions that juvenile offenders are more prone to reactive hypoglycemia than their adolescent peers.

The behavioral assessment package used to evaluate performance changes following sucrose ingestion included a series of neuropsychological tests chosen for their relevance to criminality and presumed sensitivity for detecting performance changes. These tests were not selected as specific behavioral or diagnostic indicators of criminality but as indices of the attentional, planning, and motor components essential to competent functioning. The tests are relevant to criminality in that they assess several of the behavioral and executive function impairments of life-course-persistent juvenile offenders (Moffitt, 1993). The entire data set, comprising both biochemical and performance measures, provided the unique opportunity to investigate the importance of nadir serum glucose in mediating the relation between sucrose consumption and performance in juvenile offenders. Thus, the data are useful for examining the associations among juvenile offender status, biochemical indices of glucose metabolism, and the relatively short-term consequences (i.e. 3 hr) of a moderate dose of sucrose on several motor and cognitive processes related both to criminality and to the integrity of brain function.

In this report, we examine whether Ss' nadir serum glucose values were predictive of their neuropsychological test performance following ingestion of sucrose and control breakfasts. To our knowledge, this is the first direct examination of this association.

## METHOD

### *Subjects*

Juvenile offenders were recruited from a maximum security prison for male adolescents. Potential Ss were told that the study was an investigation of the effects of nutrition on school-related behaviors. Ss between the ages of 14 and 19 yr were selected randomly from volunteers who received parental consent and whose medical records did not contraindicate participation (e.g. diabetes).

Although the original sample also included black offenders and a noninstitutionalized comparison group, we only report the results obtained from the 48 white offenders who completed the 3-day protocol (10 white offenders completed only one of two behavioral test days and therefore could not be included in the analyses described here). There are two reasons for the decision to restrict this report to data obtained from white offenders. First, because only three nonoffenders had abnormally low serum glucose nadirs, it was not possible to use the nonoffenders in the present analyses. Second, despite equivalent numbers of black and white offenders with nadir serum glucose values in the low range, random assignment resulted in only two black subjects with low nadirs receiving one of the two orders of breakfast administration. This uneven *S* distribution precluded reliable analyses with the black offenders because nadir serum glucose group interacted with the order of breakfast administration to influence performance.

### *Assessment*

The neuropsychological portion of the assessment package included the WAIS-R Digits Forward and Backward (Wechsler, 1981), Finger Tapping (Halstead, 1947), Two Minute Finger Tapping (Amelang & Breit, 1983), Trail Making A and B (Reitan, 1958), and a Continuous Performance Test [CPT (C. Keith Conners, oral communication, 1985)]. These measures were selected because of their use in prior diet and behavior studies, presumed sensitivity to performance fluctuations, and relevance for assessing motor and attention functions that might be affected by sucrose. The results from assessment measures not described in this article were administered on only 1 day of testing. They included traditional measures of learning and memory and tasks developed in our laboratory to investigate the psychological processes underlying behavioral disinhibition. These tasks assessed diverse constructs and, perhaps as a consequence, were not uniformly influenced by the substance manipulation.

The dependent variables for each measure were converted to *z*-scores so that more positive *z*-scores always reflected better performance. The conversion procedure ensured that each variable received

equal weight in analytic comparisons and enabled comparison of Ss' performance following the sucrose and no-sucrose breakfasts while controlling for day of testing (i.e. their performance was always relative to the performance of other Ss assessed on the same day of testing regardless of breakfast type).

A 32 item behavior checklist (Wolraich *et al.*, 1985) was used to evaluate a variety of observable, conduct-related variables such as inadequate attention and motivation. This behavior checklist was selected because it contained several descriptors relevant to conduct problems and because many of the behaviors assessed by the checklist have been hypothesized to be disrupted by sucrose ingestion (e.g. 'can't concentrate', 'fidgety', and 'overactive'). The checklist was not used for trait and diagnostic assessments as other, validated measures were used for these purposes. Instead, scores from the checklist were used to assess whether the ratings made by experimenters, who were blind to the type of breakfast ingested, were differentially associated with the on-task behavior and overall comportment of subjects in response to the breakfast manipulation.

Experimenters completed the checklist after each behavioral testing day by rating items on a three point scale: a score of '0' was assigned if the behavior was not in evidence, a '1' if the S exhibited the problem to a limited extent, and a '2' if the problem behavior was clearly in evidence. Analyses were conducted with six face valid subscales (Restless, Distracted, Aggressive, Impulsive, Awkward, and Insecure).

### Procedure

The experimental protocol was administered during three morning sessions, with each session following an overnight (9 hr) fast. The OSTT was administered on the first day. Beginning at 7:00 hr, Ss drank 250 ml of a 0.88 mol/l (75 g) unflavored sucrose solution within about 5 min. Fasting (15 ml) and postprandial (4 ml at 30, 60, 120, 180, and 270 min) blood samples were drawn via an indwelling venous catheter [see Gans *et al.* (1990) for additional details].

Ss consumed a sucrose-loaded (78 g) or an aspartame-sweetened (400 mg aspartame and < 1 g sucrose) breakfast on the second and third days of testing; for convenience, we refer to the latter meal as the 'no-sucrose' breakfast. The quantity of sucrose in both the OSTT and the sucrose meal is approximately equal to the amount of simple sugars in two 12 oz cans of soda. Both specially prepared breakfasts included a bowl of cereal, a cup of milk, and a glass of orange drink. Because the breakfasts were matched on sweetness, they were unmatched on other dietary characteristics. The sucrose-loaded breakfast (636 kcal) contained 80% carbohydrate, 11% protein, and 9% fat whereas the no-sucrose breakfast (470 kcal) contained 62% carbohydrate, 21% protein, and 17% fat.

The breakfasts were administered within the parameters of a randomized double-blind crossover challenge design. Each breakfast was followed by a 3 hr battery of neuropsychological tests, other behavioral measures, and psychological assessments. Behavioral testing began approx. 40 min after the completion of breakfast so that performance could be assessed during the period of time when serum glucose values were below fasting levels. Whenever possible, the two behavioral test days were scheduled 2 days apart.

Ss were separated into three groups on the basis of their nadir serum glucose value during the OSTT. The 'low' group included those Ss whose nadir value fell to 50 mg/dl or less on at least one postprandial blood sample ( $n = 14$ ) whereas the serum glucose value of the 'normal' group never dropped below 60 mg/dl ( $n = 13$ ). The remaining Ss ( $n = 21$ ) were classified as having 'borderline' nadir serum glucose values. The lower cutpoint was chosen because it has been used in earlier research (Virkkunen & Huttunen, 1982) and because it is consistent with traditional diagnostic criteria (Berkow & Fletcher, 1987). The higher cutpoint was used to isolate Ss whose glucose metabolism was not categorically impaired but whose nadir values are considered to be atypical by some diagnostic standards (see Messer *et al.*, 1990).

## RESULTS

The results of analyses reported here used data from both days of behavioral testing to provide sufficient power for determining whether nadir serum glucose influenced performance following the

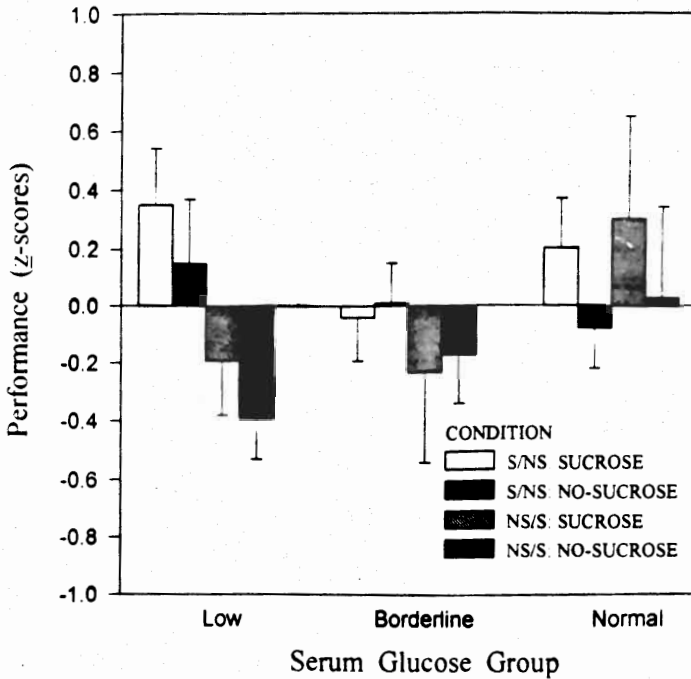


Fig. 1. Breakfast  $\times$  Order  $\times$  Nadir Serum Glucose Group performance scores averaged across the nine dependent measures obtained from Digits Forward, Digits Backward, Finger Tapping, Two Minute Finger Tapping, and Trails A and B. Error bars represent the standard error of the mean. Low:  $< 50$  mg/dl; borderline: 50–60 mg/dl; normal:  $> 60$  mg/dl.

sucrose and no-sucrose breakfasts. We omitted data from the second day of testing in an earlier report (Bachorowski, *et al.*, 1990) due to the complexities associated with interpreting crossover designs. However, because of the limited number of Ss within the low, borderline, and normal nadir serum glucose groups, performance from both days was used to provide the statistical power necessary for meaningful analysis. Two MANOVAs were conducted for the overall analysis of the performance data. Each MANOVA was a 3 (nadir serum glucose group)  $\times$  2 (order of breakfast administration) analysis, with the performance measures and two behavioral assessment days as within S variables.

The first MANOVA used performance scores obtained from Digits Forward, Digits Backward, Finger Tapping, Two Minute Finger Tapping, and Trails A and B. The analysis revealed that nadir serum glucose values (low, borderline, and normal) were related to neuropsychological performance following the sucrose manipulation. This relationship was complex in that nadir glucose also interacted with the order of breakfast administration and day of testing to influence performance [ $F(2, 42) = 4.64, P < 0.025$ ]. This three-way interaction, depicted in Fig. 1, indicated that the relationship among the three grouping factors was uniform across performance measures as indicated by the absence of a significant interaction between the dependent measures and any of these factors.

Importantly, the performance of Ss with atypically low nadir serum glucose values was not categorically deficient following sucrose ingestion. In fact, the subset of these Ss who received the sucrose breakfast on the first day of behavioral testing performed quite well following this meal. These same low nadir Ss experienced a slight performance decrement following ingestion of the control meal on the second day of testing. Conversely, those low nadir Ss receiving the no-sucrose meal on the first day performed poorly. Their performance improved after ingesting the sucrose meal on the second test day. Thus, for Ss with impaired glucose metabolism, within-subject performance was always better following the sucrose meal; the direction of performance change between the first and second test days depended upon the sequence of breakfast administration.

Ss with nadir values falling in the borderline range performed at or below average regardless of breakfast type and they performed especially poorly if they received sucrose as the second behavioral test meal. Finally, Ss with glucose nadirs falling within the normal range performed better following

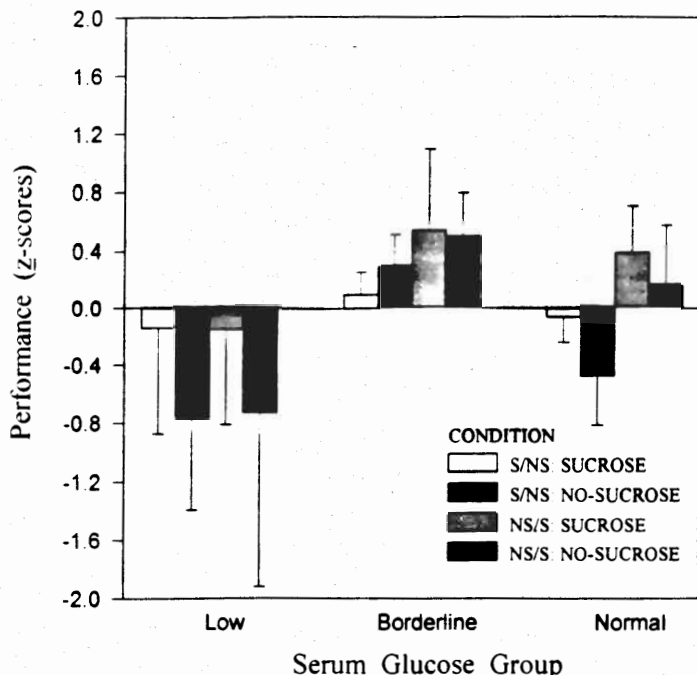


Fig. 2. Breakfast  $\times$  Order  $\times$  Nadir Serum Glucose Group performance scores averaged across CPT False Alarms and Misses for Ss with usable CPT data from both test days. Error bars represent the standard error of the mean. Low:  $< 50$  mg/dl; borderline:  $50\text{--}60$  mg/dl; normal:  $> 60$  mg/dl.

the sucrose than the no-sucrose breakfast regardless of breakfast order. Ss with normal nadir values only performed poorly if they received the no-sucrose meal on the second test day.

The second MANOVA used false alarms and misses from the CPT as the dependent variables. It was necessary to conduct this separate MANOVA with the CPT data because 17 Ss had excessive false alarms and/or misses on this task for at least one of their two exposures to this task. Ss were excluded from this analysis if 50 or more of the 800 trials were recorded as false alarms and/or misses for either day of behavioral testing. This decision rule excluded 7 Ss from the low, 6 Ss from the borderline, and 4 Ss from the normal nadir serum glucose group. The performance of excluded Ss was more likely the product of deficient motivation than ability since Ss did not begin the CPT until they demonstrated an accurate understanding of the task requirements. Z-Scores used in the analysis were calculated using data obtained from the remaining Ss. The MANOVA results indicated that nadir serum glucose group did not interact with the sucrose manipulation to affect CPT performance,  $F(2, 25) = 0.21$ , n.s. Furthermore, none of the higher order interactions were significant. The z-scores, averaged across false alarms and misses within sucrose and no-sucrose meals, are provided in Fig. 2. Although sucrose ingestion did not have a statistically significant impact on the sustained attention of Ss who varied in nadir serum glucose value, the overall pattern of results was similar to the one observed with the other performance measures. The small number of Ss remaining in each cell following the removal of Ss with very poor performance (e.g. three of the six Order  $\times$  Group cells contained only 3 Ss) and the substantial variance in performance for the remaining Ss likely contributed to the absence of strong statistical associations among sucrose ingestion, nadir serum glucose, and performance.

The 11 *post hoc* MANOVAs conducted with the dependent variables separately were not statistically significant, although trends for the interaction of breakfast type and nadir serum glucose group for Finger Tapping-dominant hand [ $F(2, 45) = 2.45$ ,  $P < 0.10$ ], Trails A-time [ $F(2, 45) = 2.45$ ,  $P < 0.10$ ], and Trails B-time [ $F(2, 45) = 2.99$ ,  $P < 0.10$ ] were obtained. The pattern of these interactions did not differ from the interaction described for the first MANOVA. This lack of strong statistical associations between the breakfast manipulation, nadir serum glucose, and particular tasks underscores the conclusion that deficient performance was not observed to be a consequence of

abnormal glucose metabolism. Furthermore, the statistical trends indicated that any performance-related effects of sucrose ingestion were more evident with tasks that involved an essential motor component (although not all measures that required a motor component interacted with nadir serum glucose values and the substance manipulation).

The primary intent of this study was to assess the effects of sucrose consumption on laboratory measures of performance rather than on overt, extra-laboratory conduct problems *per se*. However, analysis of the six subscales formed from the 32 item checklist ratings provided an index of the extent to which sucrose consumption was associated with problem behaviors during the testing sessions. The nadir serum glucose Group  $\times$  Breakfast  $\times$  Order of Breakfast  $\times$  Subscale interaction,  $F(10, 210) = 1.98, P < 0.05$ , although not particularly compelling because of its complexity, paralleled the one obtained with the performance measures. Ss with low and normal nadir serum glucose values were generally rated as having better behavior after ingesting the sucrose meal. Ratings for Ss with borderline values varied more as a function of subscale. These data, averaged across the order of breakfast administration, are provided in Table 1.

## DISCUSSION

These results suggest that the performance enhancing effects of sucrose ingestion described by Bachorowski *et al.* (1990) were specifically associated with those juvenile offenders who manifested low and normal serum glucose nadirs during the OSTT. The breakfast manipulation had essentially no impact on the performance of Ss with borderline nadir values. Remarkably, and in contrast to hypotheses that implicate reactive hypoglycemia as the mechanism underlying adverse, short-term reactions to sucrose ingestion, these data indicate that the behavior of juvenile offenders with abnormally low nadir serum glucose values is generally unaffected by sucrose consumption. If anything, the results illustrate that sucrose ingestion can have a slight but measurable performance enhancing effect on offenders with impaired glucose metabolism.

One explanation for these findings involves the interaction between the breakfast manipulation and experience with the testing situation within each nadir glucose group. Offenders with deficient glucose metabolism performed quite well when they received the sucrose meal on the first behavioral test day. In contrast to the low nadir Ss receiving the control meal on this day, the sucrose meal may have enabled these Ss to negotiate the demands of the novel and rigorous assessment. The learning that occurred after ingesting this meal may also have protected these Ss from a more serious performance decline on the second test day.

It is not yet known whether this effect can be attributed directly to sucrose because the breakfasts also differed on other potentially important properties. For example, it may have been the greater amount of energy (kcal) provided in the sucrose meal, rather than sucrose *per se*, that was responsible for the observed performance advantage, on both test days, in these metabolically impaired Ss. Thus, Ss with suboptimal physiological environments may utilize the energy available in sucrose-loaded foods to improve upon otherwise deficient performance.

The performance of offenders with seemingly normal glucose metabolism was also not impaired by sucrose ingestion. These Ss performed better after the sucrose meal regardless of whether that meal was ingested on the first or second day of testing (the performance of these normal nadir Ss only fell to below average levels if they received the control meal on the second test day). The observation that this particular group performed very well after sucrose ingestion underscores the fact that global statements about sucrose effects are ill-advised.

Understanding the performance of Ss with nadir values falling in the borderline range is perhaps the most difficult to understand from either a psychological or biochemical perspective. Although they did not manifest seriously impaired glucose metabolism, this subset of offenders demonstrated slight performance impairments following sucrose ingestion. Moreover, this group never performed at an above average level regardless of substance.

The generality of our findings is limited because we focused on neuropsychological test performance rather than more overt behavior problems. Thus, the observed sucrose effects do not necessarily pertain to the gross, criminal conduct problems of juvenile offender Ss. Nevertheless, to the extent that performing the battery of tests required concentration, memory, speed, accuracy,

Table 1. Experimenter rating means, standard errors of the mean, and difference scores within behavior checklist subscales across order of breakfast administration

Glucose nadir group	Low ( $n = 14$ )			Borderline ( $n = 21$ )			Normal ( $n = 13$ )		
	Sucrose	No-Sucrose	Difference	Sucrose	No-Sucrose	Difference	Sucrose	No-Sucrose	Difference
Restless	4.29 (1.08)	5.36 (1.32)	+ 1.07	4.24 (0.94)	3.57 (0.83)	- 0.67	4.54 (1.28)	5.85 (1.58)	+ 1.31
Distracted	1.29 (0.52)	1.86 (0.49)	+ 0.57	1.38 (0.33)	1.62 (0.41)	+ 0.24	1.23 (0.56)	1.23 (0.34)	+ 0.00
Aggressive	3.07 (1.17)	3.79 (1.36)	+ 0.72	2.67 (0.80)	1.95 (0.43)	- 0.72	1.08 (0.24)	4.15 (0.88)	+ 3.07
Impulsive	2.79 (0.65)	3.21 (0.64)	+ 0.42	2.57 (0.48)	2.62 (0.43)	+ 0.05	2.08 (0.43)	3.46 (0.76)	+ 1.38
Awkward	1.07 (0.35)	1.29 (0.42)	+ 0.22	1.48 (0.36)	1.33 (0.29)	- 0.15	0.92 (0.26)	1.92 (0.57)	+ 1.00
Insecure	1.86 (0.82)	0.79 (0.32)	- 1.07	1.33 (0.41)	1.62 (0.41)	+ 0.29	2.08 (0.50)	1.38 (0.46)	- 0.70
Total	14.36 (3.93)	16.29 (3.51)	+ 1.93	13.67 (2.16)	12.71 (1.49)	- 0.96	11.92 (2.17)	18.00 (3.18)	+ 6.08

Note: positive difference scores are indicative of better experimenter behavior ratings following the sucrose than following the no-sucrose breakfast.

response flexibility, sustained attention and the ability to apply oneself over a lengthy and rigorous session, the results are probably relevant to some of the contexts, such as academic settings, in which offenders exhibit behavior and performance difficulties. A related consideration is that several of the cognitive functions assessed by these measures have been shown to be predictive of life-course-persistent antisocial behavior (Moffitt, 1993). Finally, experimenter ratings of behavior and comporment provided no evidence that sucrose ingestion was associated with more impulsive, disruptive, or aggressive behaviors in the hours following sucrose ingestion in the laboratory setting. A second limitation to these findings is that the series of analyses described in this report could not be conducted with black and nonoffender Ss because of the inadequate number of Ss from these groups with low nadir serum glucose values during the OSTT.

The results of this investigation are notable because we examined the effects of sucrose ingestion on the performance of a group of juvenile offenders who displayed atypically low nadir serum glucose values during an OSTT. Despite objective evidence that the serum glucose responses of juvenile (Gans *et al.*, 1990) and adult (Virkkunen & Huttunen, 1982) offenders differ from controls during an OSTT and OGTT, respectively, a direct association between glucose metabolism and behavior problems has not previously been tested. Contrary to popular hypotheses, our results indicate that sucrose consumption did not impair performance in white offenders with low or with normal serum glucose nadirs during an OSTT. If anything, the performance results suggest that sucrose consumption was associated with *improved* rather than impaired performance in these metabolically impaired subjects.

These findings highlight the complexity of this area of diet and behavior research and serve to emphasize the importance of critically examining assumptions in this area. Simple generalizations concerning the effects of sucrose on the behavior of criminal offenders are misleading. In light of other existing evidence concerning the differential effects of sucrose in various subgroups of incarcerated juveniles, such as relatively hyperactive offenders (Bachorowski, 1991; Bachorowski *et al.*, 1990), the application of dietary changes that target only one nutritional component with the aim of ameliorating conduct problems is unwarranted.

The present results are provocative in their demonstration of unimpaired and improved performance in a subgroup of juvenile offenders with anomalous glucose metabolism. We hope that these findings will promote research that addresses the potential physiological mechanisms responsible for the observed relations. In this regard, one reasonable process by which sucrose ingestion could alter the behavior of disinhibited Ss is through increased serotonin synthesis via the selective uptake of dietary tryptophan (Blum, Vered, Graff, Grosskopf, Don, Hrsat & Raz, 1992; Fernstrom & Wurtman, 1971, 1972; Spring *et al.*, 1987; Young, 1991; cf. Ashley & Leathwood, 1984; Peters & Harper, 1987). Further research should also aim to elucidate the complex interaction of physiological and psychological factors that explains how consumption of sucrose comes to exert a significant influence on the performance of some juvenile offenders.

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