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The Effects of Sugar on the
behavior of young children.

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ABSTRACT

The effects of the consumption of sucrose (30 grams) on the behavior of 18 normal pre-school children, 3 - 5 years of age, were investigated in a double blind-placebo controlled study. A wide variety of measures were used including psychometric tests, an objective measure of activity level, behavior checklists and an observational behavior coding system. The overall findings were essentially negative and no dramatic behavioral effects resulted from sugar consumption. This pattern of generally negative results suggests that behavioral effects of sucrose consumption are subtle in nature and limited to a certain subset of children.

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INTRODUCTION

1.

Historical background

The belief that dietary factors can have a direct influence on behavior has become increasingly popular amongst the lay public. Although the notion that adequate nutrition is essential for the normal healthy development of a child has been accepted for some time, it is only in recent years that many people have become convinced that the nature of foods consumed may have an effect not only on physical but also on mental development.

The most publicized theory of a relationship between nutritional variables and childhood behavior is that of Feingold who suggested that artificial food colors, flavors and preservatives may play a causative role in hyperkinesis. The results of methodologically sophisticated research have, in general, failed to substantiate Feingold's dramatic claims. The only aspect of the diet investigated to date, however, is that of food dyes, and it remains possible that other nutritional variables eliminated in the diet may be responsible for the clinical improvement reported. The elimination of food additives from a child's diet necessarily also involves the elimination of many commercially prepared foods, in particular, "junk food". The Feingold diet, therefore, entails a significant reduction in the amount of carbohydrates and sugars in the diet, and it is not yet clear to what extent, if any, these factors may contribute to reported improvement in hyperactive behavior.

A reduction in carbohydrate and sugar consumption is

sometimes included in two other dietary approaches to the management of childhood behavioral disorders; megavitamin therapy and allergy-elimination diets. As is the case with the Feingold diet, these approaches remain controversial, but are frequently accepted willingly by desperate parents of hard-to-handle children. Research on the effectiveness of these and the Feingold diet will be reviewed briefly in a later section.

Excessive sugar consumption has been linked for some time with a variety of physical diseases. For example, Yudkin (1972) attributed the increased incidence of coronary thrombosis in developed countries to the vast amount of sugar consumed in these countries. Sugar consumption is reported as high as 50 - 60 kg. per capita per annum in these countries, particularly Australia, U.K. and Switzerland. The production and consumption of sucrose, or common table sugar, has shown an increase unparalleled by any other food (Aykroyd, 1974; Shannon, 1977; Yudkin, 1972). Considered a rare and highly expensive commodity, sugar remained available only to a few of Europe's most privileged citizens prior to the development of the slave trade and the establishment of sugar cane plantations in the New World (Aykroyd, 1967). The discovery of an alternate source of sucrose, beet sugar, prompted by Napoleon's embargo on trade with England, further increased the availability of sugar to the general population.

The following Figure 1 taken from Aykroyd, 1967, shows the dramatic increase in sugar consumption in the U.K., a

FIGURE 1. *

CONSUMPTION OF SUGAR IN THE UNITED KINGDOM 1815-1964

(Kilograms per head per annum)

Consumption of sugar in the United Kingdom. 1815-1964.
(Kilograms per capita per annum)

* from Aykroyd. 1967

country with one of the highest sugar consumptions. A consumption per capita per annum of between 50 - 60 kg. appears to represent a saturation point, and the level of consumption in the U.K. has remained relatively consistently at this level since 1964. The U.S.A. per capita per annum consumption is estimated at slightly less - approximately 50 kg. per year. Figure 2 illustrates world sugar consumption. Average daily consumption of sucrose has been estimated in the range of 123 - 140 grams of sugar. These figures are based on disappearance rates and not on epidemiological studies of actual amount consumed (National Academy of Sciences, 1975).

In addition to these dramatic increases in sugar consumption, there has also been a change in the form of sugar intake such that most of the sugar consumed today is in the form of "hidden sugar". In the U.S.A. in 1910, 75% of sugar consumed was in the form of "table sugar" - i.e. purchased by the consumer for use in baking or on the table to be added to beverages and cereals. During the last century dietary patterns have changed considerably along with changing lifestyles, so that commercially prepared "convenience" foods now constitute a major part of many people's diet. It is estimated that approximately 70% of the refined sugar in the U.S.A. is used by the food industry and only 30% purchased directly by the consumer (Shannon, 1977). Considerable quantities of sugar may thus be consumed unknowingly. The amount of sugar consumed in this way by children may be significantly higher than that of

Figure 2 *

World Sugar Consumption

*from Aykroyd, 1967.

adults. Children not only consume greater amounts of candies and soft drinks, but also may be given breakfast cereal that contains as much as 60% sucrose (Shannon, 1977). Table 1 lists the sugar content of some common foods.

Few studies have been conducted to determine actual daily sugar consumption of particular subgroups of the population particularly children. Yudkin (1972) estimated daily sugar consumption per capita in U.K. children to be as high as 300 grams. This represents an annual consumption of approximately 109 kg. - twice the estimated average consumption of the country. Whether this high sugar consumption amongst children has any direct adverse effect on behavior has yet to be demonstrated empirically, however, an increasing number of parents and teachers believe in the "Hallowe'en effect" and hyperactive and disruptive behavior is frequently attributed to excess sugar consumption.

Table 1

Sugar Content of Common Foods. *

<u>Food item</u>	<u>Size Portion</u>	<u>Approx. sucrose content</u>	<u>Approx. Percentage sucrose content</u>
Cherry Pie	1 slice	50 grms.	
Chocolate cake	1 slice	30 grms.	
Glazed donut	1	30 grms.	
Soft drinks	12 oz.	30 grms.	8%
Chocolate milk	10 oz. glass	30 grms.	
Rice Krispies	1 bowl & $\frac{1}{2}$ tsp. sugar	30 grms.	10%
Corn Flakes	1 bowl & $\frac{1}{2}$ tsp. sugar	30 grms.	7.8%
Malted milk shake	10 oz. glass	25 grms.	
Jello	4 oz.	22.5 grms.	30-50%
Oatmeal cookies	1	10 grms.	25%
Cheese cake	1 slice	10 grms.	
Sugar cookies	1	7 grms.	27%
Chewing gum	1 stick	2.5 grms.	60%

* Adapted from "Buying Dental Decay Through Hidden Sugars" publication of Ottawa-Carleton Regional Health Care Unit and "A Brand Name Guide to Sugar", Shannon, 1977.

(5 grms. of sugar are approximately equivalent to 1 tsp.)

(30 grms. of sugar are approximately equivalent to 1 oz.)

Chemical structure and metabolism

The term "sugar" is used through-out this paper to refer to sucrose, or common table sugar, the chemical structure of which is the same, whether produced from cane sugar or beet sugar. Since the term sugar is frequently applied to many other sugars, e.g. "blood sugar" or "fruit sugar", the following provides a brief review of the chemical structures of the sugars most important in nutrition. Sugars are divided into two major classes: monosaccharides and disaccharides.

Sucrose is classified as a disaccharide being formed by the combination of two monosaccharides, or simple sugars. The monosaccharide units that are linked together to form sucrose are glucose and fructose. A third monosaccharide considered of nutritional importance is galactose. These simple sugars share the same empirical formula, $C_6H_{12}O_6$, but have a different chemical structure as illustrated in Figure 3.

Glucose is known commercially as dextrose, and is also frequently termed "blood sugar", since it is the only sugar that plays a major role in human metabolism. Other sugars consumed are, in general, converted into glucose by the liver. Normal blood levels of glucose in humans are 80-120 mg./100 ml. blood (Mottram, 1979; Seager & Slabough, 1979). The alternative name, dextrose, refers to the direction in which solutions of glucose rotate polarized light, i.e. to the right.

Fructose, also known as levulose or fruit sugar, is the sweetest of the common sugars. The term levulose refers to the property of fructose of rotating polarized light to the

Figure 3 *

Glucose

Galactose

Fructose

Structural formulae for glucose, galactose and fructose

* from Mottram, 1979

left. Fructose is found in free form in many fruits and also in honey, which is composed of about 20% water and 75% simple sugars, i.e. fructose and glucose in equal ratios. Although many health food faddists have advocated the use of honey in preference to refined table sugar, the only difference between sucrose and honey is that, in honey the sucrose molecules have been broken down into a mixture of glucose and fructose. This breakdown or hydrolysis also occurs when sugar is cooked with foods containing acid, and in the digestion of sucrose by the enzyme sucrase.

Sucrose is one of three disaccharides important in nutrition, the remaining two being maltose and lactose. The chemical structures of these disaccharides are illustrated in Figure 4.

Maltose, also known as malt sugar, is produced in the breakdown of starch and consists of two glucose molecules joined by an acetal linkage. Lactose, or milk sugar, is unique to mammals and is the principal sugar in breast milk (Davidson, Passmore, Brock/ Truswell, 1975). It consists of one molecule of glucose linked to one molecule of galactose.

Sucrose, produced commercially from cane and beet, is also found in a variety of fruits and in the nectar of flowers. It is formed from one molecule of glucose and one molecule of fructose. The hydrolysis of sucrose, which occurs easily, produces a mixture of glucose and fructose in a one to one ratio known as invert sugar. In the human digestive system sucrose is broken down by the enzyme sucrase into fructose and glucose in the small intestine and absorbed into the blood stream.

Figure 4 *

Structural formulae for maltose, lactose, and sucrose

*from White, Hender & Smith, 1964

Fructose is absorbed more slowly than glucose, but is utilized more quickly than glucose, as its metabolism is not dependent on insulin. Fructose is converted in the liver by the enzyme fructokinase into dihydroxyacetone phosphate and glyceraldehyde in which form it can be utilized as a source of energy for the tissues (Davidson, Passmore, Brock & Truswell, 1975).

The level of glucose in the blood is regulated by secretions of insulin, glucagon and epinephrine. Insulin secretion from the islets of Langerhans in the pancreas is stimulated by elevated blood glucose levels. Insulin increases the rate at which glucose is converted into glycogen, or "animal starch" in which form it is stored in the liver. Epinephrine and glucagon have the converse effect and increase the rate at which glycogen is hydrolyzed to glucose when the level of blood glucose falls below normal fasting levels (70-90 mg. per 100 ml.) (Seager & Slabaugh, 1979; Davidson, Passmore, Brock and Truswell, 1975).

If insulin secretion is inadequate, as is the case in diabetes, blood sugar levels will rise above normal levels, producing the syndrome of hyperglycemia. If the blood sugar levels rise above the renal threshold, 150-170 mg. per 100 ml. of blood, glucose is excreted by the kidneys and appears in the urine. The presence of glucose in the urine is normally diagnostic of diabetes.

The converse condition where too much insulin is produced, hyperinsulinism, may result in lower than normal blood sugar levels of hypoglycemia. Hypoglycemia may also

be caused by fasting and by strenuous exercise in which blood glucose is depleted faster than it can be replenished from liver supplies of glycogen. The syndrome of "functional hypoglycemia" attributed to excessive carbohydrate consumption will be discussed further in the following section.

In evaluating any hypothesized behavioral effects of sucrose consumption it must be borne in mind that they must be attributed to changes in the blood glucose levels.

Intact sucrose molecules are too large to be absorbed and must first be hydrolyzed to the constituent monosaccharides (glucose and fructose) prior to absorption in the small intestine. Fructose itself is not utilized as such by muscle, heart or brain and is mostly converted to glucose by the liver. Furthermore, glucose is the only energy-yielding substrate available to the brain, which does not have the capacity to store it in any form.

Possible mechanisms involved in
behavioral reactions to sugar

Allergy

A proposed allergic basis for adverse reactions to foods including cane, corn and beet sugar has a long historical background (e.g. Coca, 1943; Ratner & Gruehl, 1935; Randolph & Yeager, 1949; Randolph & Rollins, 1950a, 1950b; Randolph, Rollins & Walter, 1950. Rowe (1930), one of the earliest proponents of the concept of food allergy, claimed that symptoms such as mental confusion, drowsiness, lack of initiative, despondency and asthenia were attributable to allergic responses to foods.

These symptoms are reported in a number of case histories of individuals said to react to corn as an allergen (Randolph & Yeager, 1949). The authors claim that such reactions were observed following consumption of corn in any form, including corn sugar, which frequently may be consumed unknowingly in such products as sweetened bacon and ham, canned fruits, or maple syrup adulterated with corn syrup.

Case history reports of reaction of fatigue, headache and mental confusion are also reported following ingestion of beet sugar (Randolph & Rollins, 1950a) and cane sugar (Randolph & Rollins, 1950b). Despite this long history, the very concept of food allergy including any possible allergic reaction to sugar, remains controversial.

The term "allergy" was first introduced by von Pirquet in 1906 (cited in Tuft, 1973) who defined it as "an abnormal reaction with characteristically unusual symptoms occurring

in man or lower animals from contact with an agent that ordinarily is innocuous to most individuals of that species."

Since this time, the term allergy traditionally has been restricted to adverse reactions involving immunological mechanisms rather than any unusual reactivity per se. This insistence on an immunologic basis for an allergic reaction raises particular difficulties in the diagnosis of food allergies. Adverse reactions to foods may be attributable to a variety of non-immunological mechanisms, e.g. enzyme deficiencies, possible toxic effects of chemical contaminants in the food, or psychological factors (Bock, 1980; Feingold, 1973; May, 1975).

Further confusion regarding the existence of food allergy arises from a failure to differentiate between food intolerance and food allergy. Food intolerance refers to a quantitative difference in the physiological reaction to a substance rather than a qualitative difference. Thus food allergy results in uncharacteristic symptoms, such as hives, rhinitis, etc., rather than an exaggeration of a normal response as might occur if normal doses of aspirin, for example, produce effects of tinnitus in a person who has aspirin intolerance (Tuft, 1973).

A differential diagnosis of an immunologic reaction to food is particularly difficult to establish since the validity of the traditional skin test used to diagnose inhalant allergies has been questioned (e.g., Mayron, 1979; Speer, 1970; Tuft, 1973). The existence of allergy is

normally indicated through the results of a positive skin test indicating the presence of an immunoglobulin. The problem arises, however, that a positive skin test is only indicative of the presence of one particular immunoglobulin (IgE) (Mayron, 1979). It is now known that IgE is only one type of immunoglobulin and that four other types exist (IgA, IgM, IgG and IgD) (Tuft, 1973). Thus, although IgE is involved in most people with inhalant-type allergy (e.g. hayfever), it is now believed that the majority of reactions to foods and chemicals involves the mediation of other immunoglobulins rather than IgE (Mayron, 1979).

Although there have been attempts to develop alternate methods of testing for immunologic sensitivities, this lack of a reliable test to determine the presence of an immunologic reaction to food, has caused much controversy amongst researchers in this area. At the present time there is a dichotomy between those who insist that a response should only be considered as allergic in nature if a reagenic (or IgE mediated) reaction can be demonstrated, and those who use the term in a more general sense of an "abnormal reaction" in which the immunological mechanisms may not be rigorously identified (May, 1975).

In considering the hypothesized relationship between food allergy and behavior, the situation becomes even more complex due to the large number and subjective nature of the symptoms which have been associated with food allergy. Table 2 provides an indication of the number of symptoms attributed to food allergy.

TABLE 2 *

SOME DISEASES AND SYMPTOMS
ATTRIBUTED TO FOOD ALLERGY BY
VARIOUS TEXTBOOKS

Migraine	Meniere's disease
Coated tongue	Belching
Transient palsy	Transient blindness
Erythromelalgia	Recurrent neuritis
Renal colic	Hypertension
Irritable bladder	Enuresis
Intermittent hydrarthrosis	Favism
Recurrent pyuria	Hematuria
Fetal hiccough	Urethral meatitis
Hyperkinesia	Fatigue
Sluggishness	Hyperesthesia
Photophobia	Torpor
Depression	Insomnia
Irrational behavior	Paranoid ideas
Feeling of unreality	Nervous tics
Inability to concentrate	Foul breath
Constipation	Recurrent diarrhea
Anorexia	Abdominal pain
Acneiform eruption	Recurrent corneal ulcer
Recurrent herpes labialis	Cheilitis
Canker sores	Pruritis ani
Blurred vision	Scintillating scotoma
Dysmenorrhea	Leukorrhea
Fever	Cardiac arrhythmia
Dizziness	Physical tiredness
Nervousness	Neuralgia
Heartburn	Indigestion

* Adapted from Feingold (1973).

Hypoglycemia

The hypothesized syndrome of functional hypoglycemia is probably simultaneously the most popular and most controversial explanation proposed to account for adverse behavioral responses to sugar consumption. Relative hypoglycemia is said to be a clinical syndrome in which a relative drop in the blood sugar level following a high carbohydrate intake is associated with symptoms referable to any system of the body (Salzer, 1966). The number of symptoms which have been attributed to this condition is perhaps only paralleled by the number of terms used to describe this syndrome. The following Table 3, adapted from Salzer (1966) and Meier (1978) summarizes the terms used to describe the syndrome and the symptoms which have been attributed to it. For the purpose of this paper the terms hypoglycemia and hyperinsulinism will be used interchangeably.

TABLE 3Terms

relative hypoglycemia
 functional hyperinsulinism
 functional hypoglycemia
 neurogenic hypoglycemia
 idiopathic hypoglycemia
 benign hypoglycemia
 functional hypoadrenal corticism
 reactive hypoglycemia
 essential hypoglycemia
 dysinsulinism
 hypoglycemic fatigue

Neurological symptoms

headache
 dizziness
 tremulousness (inward, and
 external)
 numbness
 blurred vision
 staggering
 fainting
 blackouts
 muscular twitching

Psychiatric symptoms

psychiatric depression
 insomnia
 anxiety
 irritability
 lack of concentration
 crying spells
 phobias
 forgetfulness
 unsocial or antisocial behavior
 suicidal tendencies

Somatic Symptoms

exhaustion
 fatigue
 sweating
 anorexia
 tachycardia
 cold hands and feet
 obesity
 chronic indigestion
 bloating
 abdominal spasm
 muscle and joint pains
 backache
 muscle cramps
 colitis
 convulsions

It can be seen from the above table that the diversity and subjectivity of many of the symptoms associated with hypoglycemia provide the opportunity for the use of this diagnosis as a catch-all explanation particularly in the case where no other medical diagnosis can be made readily.

The syndrome of hyperinsulinism was first described by Harris (1924), who developed a modification of the Glucose Tolerance Test (GTT) previously used in the diagnosis of diabetes. The original test consisted of an analysis of blood glucose levels in a patient in a fasting state; the oral administration of 100 grams of glucose and an analysis of blood and urine samples at half hour intervals for the next two hours (Abrahamson & Pezet, 1951). Normal fasting blood sugar is between 80-120 mg. of glucose per 100 c.c. of blood, rises to not more than 160 mg. following glucose consumption and returns to the baseline reading within the two hour period. The modification of the GTT proposed by Harris in the diagnosis of hypoglycemia extends the period of sampling the blood to a five hour period, and the blood glucose levels are analyzed at hourly intervals. The diagnosis of hypoglycemia is usually made if the blood sugar drops below 60 mg. per 100 c.c. (Hadji-Georgopoulos, Schmidt, Margolis & Kowarski, 1980) or if there is a drop of 20 mg. per cent or more below the fasting blood sugar level (Salzer, 1966). Other researchers make a diagnosis of hypoglycemia if there is a fall of 50 mg. per cent or more in any one hour period accompanied by symptoms (Schauss, 1980). Data from studies of abnormal

glucose tolerance curves show that the highest percentage of abnormalities (88%) occurs within one hour after glucose administration (Langseth & ~~W~~wd, 1978).

Diagnoses of hypoglycemia may even be made, in the absence of abnormal blood-glucose findings, on the basis of subjective reports during the test period of symptoms associated with hypoglycemia such as dizziness, sweating or lethargy (Schauss, 1980).

Hypoglycemia may also be diagnosed on the basis of a particular type of abnormal glucose tolerance curve, the so-called "flat curve hypoglycemia", in which blood sugar fails to rise 50% above the fasting blood sugar, and remains at a relatively constant level through-out the testing period (Lesser, 1980). This type of hypoglycemia is said to be accompanied by a flat, apathetic emotional state, and criminals with this type of glucose tolerance curve are said to be particularly difficult to rehabilitate (Schauss, 1980). Figure 5 illustrates the normal and abnormal GTT curves.

Treatment of hypoglycemia normally consists of placing the patient on a low carbohydrate high protein diet. Caffeine may also be eliminated from this diet on the basis that caffeine stimulates the adrenal medulla, increasing the release of epinephrine, which increases the amount of glycogen broken down into glucose in the liver. The resultant increase in blood sugar stimulates the Islands of Langerhans to release insulin. It is suggested that due to repeated stimulation the Islands of Langerhans become so sensitive that they

Figure 5 *

Typical glucose tolerance curves.

* from Bonnet & Pfeiffer (1978)

overreact to a normal stimulus and the condition of hyperinsulinism (hypoglycemia) develops (Abrahamson & Pezet, 1951).

The proposed syndrome of hypoglycemia has been publicized widely and readily accepted by the general public, who frequently make a self diagnosis of the syndrome to account for a myriad of vague complaints including chronic fatigue, anxiety and "mental dullness". Other researchers, however, have argued against the concept of hypoglycemia as a medical condition, and are particularly concerned about the widespread public acceptance of the syndrome, referring to self-diagnosed hypoglycemia as an "epidemic condition" (Yager & Young, 1974; Cahill & Soeldner, 1974). These authors point out a number of reasons why hypoglycemia has become so popular amongst the lay public. For example, the person is able to ascribe his vague symptoms and complaints to a metabolic disorder rather than accept the socially unacceptable diagnosis of a psychological or psychiatric disturbance. The person is also provided with the opportunity of self-control over the management of his own treatment.

Arguments against the concept of reactive hypoglycemia associated with behavioral or physiologic symptoms have been based on evidence from patients with inoperable insulin-producing tumours and diabetic patients who take multiple injections of insulin in an attempt to achieve greater control of their blood sugar levels. These patients have been reported as asymptomatic with blood glucose levels as low as 20-30 mg. per 100 ml. (Cahill & Soeldner, 1974).

Moreover, reports of symptoms of diabetic patients who have taken an excess of insulin, in general, have not included the symptoms associated with reactive hypoglycemia such as anxiety, mental dullness, or loss of energy (Caill & Soeldner, 1974).

Further arguments against the concept of hypoglycemia have centered on the use of GTT results as the basis for diagnosis. It is tempting to presume that, although self-diagnosis of hypoglycemia may, in fact, be a diagnosis of "non-hypoglycemia", abnormal GTT results would allow a more scientifically credible diagnosis of a true metabolic disorder. The problem arises, however, in interpreting the GTT results, since 23% of the normal population have blood glucose levels below 50 mg. per 100 ml. over a five hour test period (Caill & Soeldner, 1974), and even values below 35 mg. per 100 ml. have been reported in asymptomatic normal persons (Park, Kahn & Gleason, 1972). Moreover, evidence suggests that the interpretation of GTT curves in children may be more difficult than in adults due in part to age-related increases in insulin levels (Rosenbloom, Wheeler, Bianchi, Chin, Tiwary & Grgic, 1973).

The acceptance of a diagnosis of relative hypoglycemia to account for a variety of behavioral disturbances must be considered in the same light as that of food allergy. Each diagnosis is not only associated with a multitude of vague, subjective symptoms but is also considered controversial by medical and scientific establishments.

Alterations in neurotransmitter synthesis

Recent research on nutrition and behavior has been interpreted as indicating that diet may influence brain neuronal activity by modifying the rate of synthesis and release of specific neurotransmitters (Fernstrom & Wurtman, 1974; Wurtman, Hefti & Melamed, 1981; Chiel & Wurtman, 1974; Fernstrom, 1981; Lieberman & Wurtman, 1982). Synthesis of a number of brain neurotransmitters such as acetylcholine, serotonin and the catecholamines (dopamine and norepinephrine) has been shown to be dependent on brain levels of their dietary precursors, i.e. choline, tryptophan, and tyrosine respectively (Fernstrom, 1977). The relationship between these dietary precursors is shown in the following figures 5 and 6. It is suggested that if diet can have a direct influence on neurotransmitter systems which are associated with distinct types of behavior, this could provide a physiological mechanism through which dietary factors could affect behavior directly (Lieberman, Corkin, Spring, Growdon & Wurtman, 1982). Of particular interest to research on behavioral effects of sugar is the finding that differences in the protein-carbohydrate ratio of a meal may affect the relative availability of the precursors tryptophan and tyrosine (Fernstrom & Wurtman, 1971; Wurtman, Hefti & Melamed, 1981).

Tryptophan is an "essential" amino acid, i.e., it cannot be synthesized by mammalian cells (unlike tyrosine which can be synthesized in the liver). Since tryptophan

Figure 5 *

Figure 6 *

Dietary precursors, catecholamine and serotonin synthesis.

* from Rolfe (1979)

is found in animal protein it was originally proposed that the consumption of animal protein would increase the levels of both plasma tryptophan and brain tryptophan, thereby increasing serotonin synthesis (Fernstrom & Wurtman, 1971). Paradoxically, the opposite findings were obtained in animal research, i.e. the consumption of a diet of animal protein containing tryptophan, although increasing levels of blood tryptophan concentrations does not lead to an increase in brain tryptophan concentrations or stimulate serotonin synthesis (Fernstrom, Larin & Wurtman, 1973). In fact, the ingestion of a high carbohydrate meal containing no proteins has been shown to increase brain tryptophan levels and serotonin concentrations (Fernstrom & Wurtman, 1971).

This paradoxical effect is explained by the fact that tryptophan shares a common transport mechanism for uptake into the brain with five large neutral amino acids (LNAA); leucine, isoleucine, valine, tyrosine and phenylalanine. This is illustrated in Figure 7, taken from Fernstrom (1980). The amount of tryptophan uptake in the brain is, therefore, dependent on the ratio of blood tryptophan to the other LNAA. A high protein meal, therefore, while increasing levels of blood tryptophan is also associated with corresponding increases in the remaining LNAA with which tryptophan must compete for transport into the brain. Due to the relative scarcity of tryptophan in dietary protein as compared with the other LNAA, a decrease in the plasma tryptophan LNAA ratio occurs following the ingestion of a high protein meal. Decreased rates of serotonin synthesis have been shown in rats fed a high protein diet (Fernstrom & Wurtman, 1974).

Conversely, an increase in brain tryptophan uptake associated with increased serotonin synthesis has been reported following the ingestion of a high carbohydrate meal (Wurtman, Hefti & Melamed, 1981). Changes in the plasma tryptophan LNAA ratio in favor of tryptophan occur due to the effect of insulin. The secretion of insulin stimulated by ingestion of a high carbohydrate meal results in the selective reduction of the levels of LNAA other than tryptophan (Fernstrom, 1977). Tryptophan levels do not fall following insulin secretion, due to the fact that tryptophan unlike the other LNAA has a tendency to bind to albumin; 80 per cent of blood tryptophan is albumin-bound. The secretion of insulin increases the availability of albumin by facilitating uptake of nonesterified fatty acids previously bound to albumin. Plasma levels of albumin bound tryptophan increase resulting in an increase in the total amount (i.e. albumin-bound plus free) of tryptophan in plasma. It is this increase in total amount of plasma tryptophan that changes the ratio of plasma tryptophan to LNAA and increases the amount of tryptophan available for uptake into the brain (Fernstrom, 1977; Wurtman, Hefti & Melamed, 1981).

A functional relationship between the consumption of a high carbohydrate meal, increased tryptophan uptake and serotonin synthesis, with behaviors mediated by serotonergic mechanisms has yet to be demonstrated. However, tryptophan poor diets (corn) fed to weanling rats increased sensitivity to pain (Lytle, Messing, Fisher & Pehbus, 1975) and tryptophan (50 mg./kg.) administered to healthy adults reduced pain

sensitivity (Dewart, Seltzer, Pollack & Jackson, 1982). Similarly, Hartman (1982) reviewed a number of human studies in which dosages of tryptophan improved sleep.

The proposed mechanism discussed above, in which the availability of dietary precursors of specific neurotransmitters increases the synthesis and release of these neurotransmitters, appears to offer a more scientifically plausible explanation for dietary effects on behavior than the controversial theories of hypoglycemia and food allergies. However, a number of problems should be considered before accepting this explanation for any reputed behavioral effects following sugar consumption. According to this hypothesis the consumption of sucrose, as a high carbohydrate food, leads to an increase in the synthesis and release of serotonin. The behavioral effects of increased serotonin synthesis are said to be decreased sleep latencies (Hartman, 1982) and increased subjective feelings of drowsiness and decreased vigour (Lieberman et al., 1982). Anecdotal and clinical reports, conversely, have linked the consumption of sugar with a number of behavioral disturbances particularly hyperactivity. Although the role of serotonin in hyperactivity and minimal brain dysfunction remains controversial (Ferguson, Pappas, Trites, Peters & Taub, 1981) previous animal (Brase & Loh, 1975) and human literature (Coleman, 1971) has associated hyperactivity with serotonin deficiency. In addition, decreases in amount of hyperactive behavior have been associated with increased serotonin synthesis (Coleman, Tippet, Bhagavan, Coursin, Gross, Lewis & Deveau, 1979). These findings, therefore,

appear to be in direct antithesis to the anecdotal reports proposing a relationship between sugar consumption (presumably associated with increased brain tryptophan uptake and increased serotonin synthesis) and increased hyperactive behavior.

A second problem in evaluating the significance of variations in availability of dietary precursors of neurotransmitters and behavioral effects concerns the applicability of experimental findings to everyday life situations. Much of the research conducted in this area has been with animals kept in highly controlled situations, usually including overnight starvation and the feeding of specific amino acid mixes. Human studies on the effects of tryptophan on sleep have used oral dosages of tryptophan in addition to consumption of high carbohydrate meals, and it has been suggested that the consumption of a single meal either high carbohydrate or high protein could not produce sufficient change in the plasma tryptophan LNAA ratio to result in changes in neurotransmitter synthesis (Leathwood, 1982; Ashley, Barclay, Chauffard, Moennoz & Leathwood, 1982).

A third problem to be considered in evaluating the theory that dietary precursors may have a direct effect on behavior is that almost all the work in this area has been published by the same group of researchers (Wurtman and his co-workers) and should be replicated by other researchers.

Research on therapeutic dietary regimes which
restrict sugar consumption

A number of dietary regimes are now advocated as alternative methods of treatment for childhood psychopathologies ranging from autism and childhood schizophrenia to hyperactivity and learning disorders. Since a number of these diets necessarily entail a reduction in sugar consumption, for example, allergy elimination diets, mega-vitamin treatment, and the Feingold diet, the following is a brief review of research to date on dietary approaches with consideration as to the possible role of sugar.

Allergy elimination diets

The use of specific diets which are designed to eliminate foods to which an individual is allergic has been advocated in the treatment of a variety of disorders including learning difficulties and hyperactivity (Rapp, 1978; Crook, 1980). However, unfortunately very little controlled research has been conducted to evaluate the efficacy of this approach to treatment.

Rapp (1978) placed 24 hyperactive children on a one-week experimental diet, which eliminated milk, wheat, eggs, cocoa, corn and sugar in all forms. Each of these foods was then re-introduced one per day and the parents were instructed to look for any "change in activity or behavior", or other physical symptoms such as aching muscles or joints. Eight of the 24 children are said to have become more active following sugar consumption.

The effects of particular foods on the disruptive behavior of an eight year old autistic boy have been investigated in a rather unique, and ethically questionable, single case study (O'Banion, Armstrong, Cummings & Strange, 1978). No attempt was made to determine whether the child suffered from food allergies, but it was assumed that any adverse behavioral

reaction to a particular food would be allergic in nature. The child was maintained in an experimental room for the entire period of a 31-day study, and observed over a four-day baseline period, during which time he consumed normal food; a six-day fasting period, in which only spring water was allowed; and an eighteen-day experimental period in which single foods were presented at four-hour intervals. The introduction of specific common foods (wheat, corn, tomatoes, sugar and dairy products) is said to have caused dramatic increases in "disruptive behavior", percentage of time spent laughing, and amount of activity. The length of time between food consumption and "reaction" is said to have varied considerably for different foods. For example, activity rate peaked at about 24 hours following consumption of wheat, whereas the reaction to cane-sugar was "immediate and short-lived" (30 - 40 minutes). While it may be reasonable to assume differential latency and duration of reactions for specific foods, unfortunately there is not sufficient data at the present time to support this assertion. The possibility remains that increased activity, interpreted as a delayed reaction may, in fact, have been unrelated to the consumption of a particular food. The fourth phase of this study would have provided more convincing results since it was designed to maintain the child on foods to which he had not shown a reaction. Unfortunately, this phase of the study, which did show a relatively low level of disruptive behavior, was terminated after four days due to loss of volunteer observers, and the death of the child's mother.

Megavitamin treatment

Megavitamin therapy has been used in the treatment of

such diverse disorders as mental retardation, hyperactivity, learning disabilities, epilepsy, childhood schizophrenia and autism (e.g. Cott, 1971, 1972; Krippner and Fischer, 1973; Rimland, 1973). The treatment with large doses of niacinamide, ascorbic acid, pyridoxine, vitamin E, and calcium pantothenate is frequently associated with recommendations for a "hypoglycemic" diet, which eliminates foods containing high levels of refined carbohydrates and sucrose (Cott, 1971; 1972; 1974; 1977). A dramatic decrease in hyperactivity is claimed when the child is placed on this diet.

One of the few double-blind studies to investigate the efficacy of megavitamins in the treatment of learning disabilities also included a low carbohydrate - high protein diet as recommended by Cott (Kershner & Hawke, 1978). All children were placed on this diet, whether they were assigned to the vitamin or the placebo group, partly as a means of maintaining the double-blind nature of the experiment. No significant differences were found between the vitamin and placebo groups on pre- and post-testing, and all children showed improvements on a behavioral checklist rated by the parents. It is suggested that the diet may have helped reduce symptoms of hyperactivity, however, the absence of a placebo diet control group makes this interpretation somewhat tenuous. A tendency to show behavioral improvement on a second behavioral rating has been reported previously (Werry & Sprague, 1974).

Feingold diet

The Feingold, or Kaiser-Permanente (K-P) diet, which emphasises the removal of artificial food additives from the child's diet is the most popular and well-known dietary treatment in use with children today. It has also been the subject of the most rigorously controlled research. The acceptance by, and popularity with, the general population is evidenced in the number of families on the diet, estimated as more than 20,000 (Morrison, 1978), and the number of local Feingold associations, more than 130 (Feingold, 1981). The controversy the diet has aroused in the scientific community may be seen in the number of studies designed to investigate Feingold's claims, at least 16 of which have been published since 1976.

The original Feingold diet emphasized the removal of natural salicylates, which have a similar chemical structure to aspirin, for example, tartrazine, and are said to cause similar reactions in aspirin-sensitive individuals (Feingold, 1974). Later modifications of Feingold's theory, now emphasize a pharmacological rather than an allergic basis for reactions to food dyes, and have led to corresponding changes in the diet itself. The emphasis now is placed, not on salicylates, but on all food additives, colorings, flavors, and preservatives (Feingold, 1979). The child is essentially placed on a diet which eliminates most commercially prepared food especially so-called "junk-food". Since much of this junk food also contains large amounts of carbohydrates,

particularly sugar, the modified Feingold diet entails a significant reduction in the amount of sugar consumed. Prinz et al. (1980) in an evaluation of dietary records of children on the Feingold diet reported considerable overlap between sugar products and foods not permitted on the Feingold diet, with 85.9% of food entries classified as sugar products not permitted on the Feingold diet.

Research on the effectiveness of the Feingold diet has left a number of unresolved issues. Open clinical trials and individual case reports in general have provided positive results, while controlled experimental studies have produced results which are at best conflicting. A number of early studies on the Feingold diet confirmed Feingold's hypothesis in that dramatic reductions in hyperactive behavior were reported following implementation of the Feingold diet (Feingold, 1973; 1974; Cook and Woodhill, 1976; Salzman, 1976; Brenner, 1977). However, these studies have received much criticism (e.g. Werry, 1976; Mattes, 1983) for the failure to use objective measures of behavior, or to attempt to control for "placebo effects" with the use of control groups or "blind" observers. Reports of behavioral improvement are based solely on the subjective accounts of parents fully aware of the nature of the study.

More rigorous research on the effects of the Feingold diet has been conducted using two experimental paradigms: "diet cross-over studies" and "challenge" experiments. In the first approach, groups of hyperactive children are placed

on two different experimental diets, one of which is the Feingold diet and the other designed to be equally difficult to follow and nutritionally equivalent. Each child is placed on both diets with the order of presentation randomized over time in a "double-blind" procedure, in which neither the child, the parents, nor the investigators are aware of the diet sequence.

Diet cross-over studies of the Feingold hypothesis have been conducted by only two groups of researchers, Conners and his co-workers (Conners, 1980; Conners, Goyette, Southwick, Lees and Andrulonis, 1976) and Harley and his associates (Harley, Tomasi, Eichman, Matthews, Chun, Cleland & Traisman, 1978; Harley, Matthews & Eichman, 1978). Results of these studies were essentially negative, although a number of interesting inconsistencies were found. For example, Conners et al. (1976) suggested that when the data were considered individually four or five children were rated as improved by both parents and teachers, and Harley et al. (1978) found in a diet study of ten pre-schoolers, all ten of the mothers rated their child's behavior as improved on the experimental diet.

Interpretation of the significance of these findings is made difficult by the fact that, in two of the three diet studies, there was a significant order effect. That is, differences in favor of the experimental diet were found only in the instance where the control preceded the experimental diet. Moreover, a significant improvement in behavior on the Feingold diet is reported on teachers' and not parents' rating

in one study (Conners et al. 1976) and the converse pattern in the study of Harley et al. (1978).

The second approach, "challenge studies", is based on the selection of children who are believed to show a favorable response to the Feingold diet. The children are maintained on this diet for the entire study period, during which time they are "challenged" with cookies or juice containing food dyes or a placebo cookie or juice designed to look and taste the same but not containing food dyes. Order of presentation of these challenges is again randomized in a "double-blind" procedure.

This approach has a number of advantages over the diet cross-over studies, which have received criticism in that the design actually compares two different experimental diets, i.e. the Feingold and the control (Rapp, 1978). Diet studies are also costly and time-consuming and, due to the tremendous popularity and amount of publication the Feingold diet has received, it may be virtually impossible to maintain strict "double-blind" procedures when concerned parents are aware that particular foods such as tomatoes or oranges are eliminated in the Feingold diet.

Challenge studies with food dyes on both group and single subject data have now been conducted by a large number of researchers (Adams, 1981; Conners, 1980; Gittleman, 1982; Goyette, Conners, Petti, & Curtis, 1978; Harley et al., 1978; Levy, Dumbrell, Hobbes, Ryan, Wilton & Woodhill, 1978; Mattes & Gittleman-Klein, 1978; Rose, 1978; Swanson &

Kinsbourne, 1980a, 1980b; Weiss, Williams, Margen, Abrams, Cann, Citron, Cox, McKibben, Orgar & Schulz, 1980; Williams, Cram, Tausig & Webster, 1978). Once again the results of these studies generally have been negative and failed to support Feingold's initial claims of dramatic responses to food dyes. However, a number of inconsistencies and occasional positive findings are again found.

Mattes and Gittelman in a single-subject design, although finding no significant differences on either parent or teacher rating scales, report that the child's mother was able to identify the "active" cookie condition correctly eight out of ten times. Levy et al. reported significant improvements on maternal ratings of behavior, but only in the condition in which the mothers were not blind to treatment condition. Williams et al., in a study to compare the relative efficacy of diet versus medication in the treatment of hyperactivity, report a significant improvement on teacher rating scales, but only when the children were receiving placebo medication.

The suggestion from the previous diet studies that younger children may be particularly sensitive to the effects of food dyes (Harley et al., 1978) is supported by a number of challenge studies. Deterioration in performance on a visual-motor tracking task administered one-hour after challenge with food dyes is reported amongst a younger sub-sample in two studies (Goyette et al., 1978; Conners, 1980). Similarly, Weiss et al. report a dramatic effect of food dye challenge was found in only one of a sample of 22 children - the

youngest child (a 2.5 year old girl).

The challenge study which has been cited as providing the strongest evidence in support of food dyes is that of Swanson and Kinsbourne (1980). Using increased dosages of dye (100 mg. and 150 mg. as compared to most challenge studies which used 26 mg. of dye) impairment in performance on a paired associate learning task is reported for hyperactive children following challenge with both dosages. This effect was not found in the control group of children. These findings, however, have received much criticism both of the design of the study itself and of the authors' interpretation of their findings (Ferguson, Rapoport & Weingartner, 1981; Forsyth, 1981; Wender, 1980). Reservations have been expressed regarding the subject groups, which were each selected from subjects sharing similar presenting symptoms, and the differentiation into the hyperactive versus the control group was made on the basis of response to medication. The "hyperactive" group in this case is actually comprised of hyperactive children (scoring an average of 16.2 on the Conners' hyperactivity scale) who responded favorably to medication, versus a slightly less hyperactive "control" group (scoring an average of 12.3 on the Conners' hyperactivity scale) who showed an adverse response to stimulant medication. This method of classifying children on the basis of response to medication as measured by the paired-associate learning task is unique to Swanson and Kinsbourne, and has been questioned (Ferguson et al., 1981; Wender, 1980) in the view of the difficulty of

differentiating between positive and adverse drug responders on the basis of psychological tests (Ferguson & Trites, 1980) and research indicating that normal children show similar behavioral and cognitive responses to stimulant drugs (Rapoport, Buchsbaum, Zahn, Weingartner, Ludlow & Mikkelsen, 1978).

A second major criticism has been made regarding Swanson and Kinsbourne's analysis of the data. A significant three way interaction is interpreted as "suggesting a rapid onset of the effect of food dyes". Visual examination of the data, however, appears to illustrate remarkably similar performance curves for both groups under dye challenge conditions and for the non-hyperactives at baseline. The major difference between the control and the hyperactive children appears to occur under the placebo conditions, in which case the hyperactives, for some unexplained reason do not show a similar deterioration over time (Ferguson et al., 1981; Forsyth, 1981; Wender, 1980).

In summary, interpretations of the results of controlled research have both failed to confirm Feingold's initial claims, and at the same time failed to allow a complete rejection of the hypothesis. Despite generally negative findings a number of trends have emerged consistently in experimental research which are consistent with the theory that food additives may have a direct, adverse effect on behavior. For example, there is a suggestion in the literature that food colors may have a transient effect on behavior, particularly in tasks requiring attention (Conners, 1980; Goyette et al., 1978; Swanson &

Kinsbourne, 1980). Moreover, several studies have suggested that a small proportion of subjects, particularly younger children, may be particularly sensitive to additives (e.g. Weiss, Williams, Margen, Abrams, Cann, Citron, Cox, McKibben, Orgar and Schulz, 1980; Harley et al., 1978; Conners, 1980). This finding of greater sensitivity of younger children has been interpreted as providing support for a toxicological reaction to food additives, as younger children appear to be at a greater risk for other toxicological effects such as methyl-mercury or lead poisoning (Weiss, 1982).

Proponents of the Feingold hypothesis have criticised the research designed to evaluate its efficacy (Feingold, 1981; Brenner, 1983). Diet cross-over studies, as mentioned previously, have a number of methodological weaknesses associated with their design particularly with attempting to maintain double-blind procedures. Challenge studies also have been criticised in that the only aspect of the Feingold diet to be subjected to rigorous challenge studies has been food colorings even though Feingold himself has disputed whether food dyes are most important (Feingold, 1981; 1982). The possibility that clinical reports of behavioral improvement may be attributed to other nutritional variables, for example, sugar, remains to be investigated, particularly in view of the finding that open studies continue to confirm that approximately fifty per cent of children do show improvement on the Feingold diet (Conners, 1980).

Sugar and behavior: anecdotal reports

As is the case with physical diseases (see Yudkin, 1972) a number of behavioral and psychiatric disorders have been linked with excessive sugar consumption. These disorders range from schizophrenia to delinquency, violent behavior, hyperactivity and learning and reading disorders (e.g. Meiers, 1973; Schauss, 1980; Yaryura-Tobias & Neziroglu, 1975; Cott, 1971; and Levin, 1978). The role of sugar in the etiology of these conditions must be considered as controversial as that associating sugar with such physical ailments as coronary thrombosis. The situation in relation to proposed behavioral effects, however, is often compounded by lack of specificity of diagnosis, particularly in the case of such poorly defined syndromes as hyperactivity and learning disabilities. The evidence which has linked sugar with these disorders is largely anecdotal in nature and is discussed briefly in the following sections.

Sugar and schizophrenia

A relationship between "relative hypoglycemia" and schizophrenia has been proposed by Meiers (1973), and is frequently accepted by orthomolecular psychiatrists. While no claim is made that relative hypoglycemia is specific to schizophrenia, it is suggested that many of the symptoms, e.g. fatigue, depression, confusion and anxiety may also be seen as the first symptoms of schizophrenia (Cott, 1969), and that relative hypoglycemia is present in up to 70% of

schizophrenic patients (Meiers, 1973). Treatment with a low carbohydrate high protein diet has been recommended for any patient presenting with schizophrenic symptoms, although no information is provided on the number of patients who respond to dietary treatment (Meiers, 1973).

Sugar, violent behavior and criminality

There is an increasing amount of literature linking hypoglycemic disorders and excessive sugar consumption with violent, criminal and delinquent behavior (e.g. Virkkunen & Huttunen, 1982; Yaryura-Tobias & Neziroglu, 1975; Schauss, 1980; Hippchen, 1978; D'Asaro, Groesbeck & Nigro, 1975). This literature may be of particular interest to any research concerning the proposed relationship between hyperactivity and learning disorders and sugar consumption, since a number of retrospective studies have shown a relationship between learning disorders and delinquency (e.g. Critchley, 1964; Mauser, 1974; Pincus, Lewis, Shanok, & Glaser, 1979).

Once again this literature is anecdotal in nature and only provides evidence that many criminal inmates consume more caffeine and sugar than non-inmates (e.g. D'Asaro et al., 1975; Hippchen, 1978). A greater incidence of abnormal glucose tolerance (GTT) results has also been reported amongst violent offenders who had an antisocial personality, as compared with a control group of violent offenders who did not have an antisocial personality, and a control group of psychiatric personnel (Virkkunen & Huttunen, 1982). An attempt to provide some evidence of a causal relationship between

abnormal glucose tolerance test results and aggressive behavior has been made by Yaryura-Tobias and Neziroglu (1975). The first author has proposed a triad relationship between aggressive behavior, functional hypoglycemia and cerebral dysrhythmia; the "behavioral-glucose dysrhythmia triad" (Yaryura-Tobias, 1973). Four groups of patients with this diagnosis, as determined by an aggression scale, abnormal GTT results and abnormal electroencephalograms (EEG's) were studied over a one to four month period. Patients in the experimental group were placed on a hypoglycemic diet (low carbohydrate, high protein, high fat) and were also given either diphenylhydantoin (D.P.H.), an anticonvulsant, or pyridoxine (vitamin B₆). The remaining groups were given respectively diet alone; D.P.H. or pyridoxine alone, and tranquilizers. A significantly greater reduction in scores on an aggression scale is reported for the experimental group. While this finding is of interest, a number of methodological weaknesses make the results difficult to interpret. Firstly, the experimental group was almost three times as large as the remaining three groups, and no information is provided as to the basis upon which subjects were assigned to each group. Secondly, the number of subjects receiving D.P.H. in relation to the number receiving pyridoxine is not given, nor is the basis for the choice between the two treatments.

Sugar and learning disabilities

The literature relating learning disabilities in children with excessive sugar consumption not only suffers from being largely anecdotal in nature but is also subject to confound in that high sugar intake in children frequently is associated with high caffeine consumption in the form of sugar in tea (especially iced tea), cola drinks and chocolate bars.

Powers (1975) reported a number of case studies of children ranging in age from four years to twenty-one years who were referred to his clinic in Dallas, Texas for complaints including hyperactivity, psychosomatic complaints, irritability, inattention and poor school performance. Sugar consumption, in a series of 50 children referred to his clinic is said to range from approximately 50 to 70 teaspoons (or 250 to 350 grams) of sugar per day. Improvement in school performance and reduction in behavior problems are described following a reduction in refined sugars and caffeine in the patient's daily diet.

A similar study of the effects of caffeine and sugar consumption of the school age population also in Dallas, Texas was conducted by Palmer (1977). In this region, there is a cultural practice of giving sugared tea in a baby bottle to young babies "to keep the baby happy". The taste for sweetened tea is, therefore, acquired very early, and in many families young children may consume significant amounts of both sugar and caffeine. Information on daily caffeine and sugar intake, dietary source, and age of onset of regular caffeine consumption

was collected from 240 students in grades four, eight and twelve in metropolitan Dallas. Ninety-five per cent of these students reported drinking a caffeine-containing beverage on a regular daily basis, and 49% reported learning to drink tea at or before age six. Of those who drank tea, 9% are said to have added one or more teaspoons of sugar per glass. Unfortunately further dietary information was not collected to allow an estimate of average daily sugar consumption including that contained in other sweetened drinks and foods.

No significant differences were found between high and low achievement groups in comparisons of high, moderate or low intake of tea and caffeinated drinks. However, when the high intake group was further broken down to form a category of "dietary abuse of tea and cola", a significant difference was found between the high and low achievement groups, with a greater frequency of dietary abuse in the low achievement group. Palmer concludes that this finding indicates a need for further research into nutritional and dietary factors in students suffering from learning disorders or general underachievement. Although the results of this study are interesting, a number of factors make their significance in terms of a possible relationship between learning difficulties and high sugar intake difficult to evaluate. For example, the breaking down of the high intake group into a category of "dietary abuse of tea and cola" appears to have been done on a strictly post-hoc basis in the absence of significant findings from previous analyses. Moreover, there was no attempt to quantify actual sugar intake or

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to separate the possible effects of caffeine and sugar. No information is provided on a number of other variables, such as socioeconomic status, which may have confounded the results.

A possible role of high sugar consumption in children with reading disorders has also been proposed (Charlton-Seifert, Stratton & Williams, 1980). The authors report that results, from a nutritional questionnaire given to parents of children referred to a reading clinic, suggest that the majority of these children consume candy, soft drinks and other kinds of "junk food". The authors also claim that, following elimination of these foods, improvement is seen in the child's ability to concentrate. Unfortunately, no information is provided on the dietary habits of children not experiencing reading difficulties, nor are any data provided on either the amount of improvement or the percentage of children who do benefit from this nutritional treatment.

Cott (1971; 1974) also makes the claim that the diet of brain-injured, hyperactive, learning-disabled and psychotic children is high in cereals, carbohydrate foods and those prepared with sugar, although once again there is no attempt to compare the diet of these children with that of normal children. It seems probable that many normal children who are not experiencing academic or behavioral difficulties may consume a similar diet. Palmer, Rapoport and Quinn (1975) found no significant differences between the diet of hyperactive boys and that of matched normal controls. Similarly, no significant differences in consumption of sugar products or in the

ratio of sugar products to other nutritional foodstuffs, such as proteins or carbohydrates, were found in the diets of hyperactive and normal children (Prinz, Roberts & Hartman, 1980).

A recent study on refined carbohydrate intake, hair cadmium levels and cognitive functioning found a significant negative correlation between the proportion of refined carbohydrates in the children's diets and I.Q. and school achievement scores (Lester, Thatcher & Munroe-Lord, 1982).

This relationship remained significant in subsequent analyses using possible confounding factors such as age, sex, and SES as co-variates. Although this study was correlational in nature the authors suggest that the consumption of foods low in nutrient value and high in sucrose may contribute to childhood learning disorders.

A number of difficulties associated with the data presentation must be considered in evaluating the results of this study. Unfortunately, no information is provided on the actual SES of the children participating in the study. This is particularly important in view of the reported lack of correlation between SES and consumption of a high proportion of refined carbohydrates. Ninety-seven per cent of the children are reported as living in rural communities. It may be assumed, therefore, that these children comprised a relatively homogeneous group of lower SES children, thus making it unlikely for significant relationships to be shown between SES and other variables.

Intelligence test scores for the subject population are reported to range from 44 to 150 with a mean I.Q. of 109.

Mentally retarded children must therefore have been included in this sample, and although again no information is provided as to the number of these children included. Moreover, the linear regression line presented showing a relationship between diet proportion of refined carbohydrates and Full Scale I.Q. is cut off at 80 I.Q. points and does not provide any information on the unknown number of children with I.Q.'s below this.

Sugar and hyperactivity

Abnormal patterns of glucose metabolism have been suggested by a number of researchers as a possible cause of hyperactivity (e.g. Levin, 1978; Cott, 1971, 1974; Langseth and Dowd, 1978). Other authors have implicated allergic reactions to both cane and beet sugar as an etiological basis for hyperactivity (e.g. Crook, 1977; 1980; Rapp, 1978).

In a study of 265 hyperactive children Levin (1978) reported that 74% had abnormal glucose tolerance curves, and that the time of greatest hyperactivity correlated with the lowest level of blood sugar. Improvement in 70 to 80 per cent of hyperactive children, in terms of "elimination of hyperactivity" and improvement in learning abilities, is claimed following treatment with a high protein, low-carbohydrate therapeutic diet.

Langseth and Dowd (1978) have also reported abnormal glucose tolerance curves in 74 per cent of the hyperactive children who participated in their study. Four types of abnormal GTT curves were found, with the "flat curve hypoglycemia" accounting for 50 per cent of these abnormal findings. The

authors report reduction in hyperkinetic behaviors in children with abnormal GTT results placed on a high protein and low carbohydrate diet. Recurrences of hyperkinetic behaviors are reported associated with the ingestion of large amounts of sugar. Unfortunately, no quantifiable data are reported in support of these statements.

The possible role of sugar as an allergen as a "leading cause of hyperactivity" has consistently been proposed by Crook (1976; 1977; 1980). Sixteen out of 55 hyperactive children referred to an allergy clinic were found to be sensitive to cane sugar (Crook, 1976). In a later study with 136 hyperactive children, Crook (1980) again claimed that sugar was the principal etiological factor in hyperactivity with sugar "causing hyperactivity" in 56% of the total group. A number of case histories are also reported in which elimination of sugar is said to have resulted in significant improvement in behavior, with dramatic deterioration associated with the consumption of as little as one teaspoon of sugar. This group, however, must be considered a highly selected group, having been referred to the allergy clinic. Moreover, in the absence of more objective data, this may be more a reflection of the extent of parental beliefs rather than an indication of the existence of adverse behavioral reactions to sugar.

In summary, there is a considerable amount of anecdotal literature linking excessive sugar consumption with a variety of negative behaviors in both adults and children. Of most relevance to the present study is that, in children, high sugar intake has been associated with hyperactivity and

learning difficulties. Improvement in behavior and academic skills is reported in children placed on sugar-restricted diets. Unfortunately, very little quantifiable data is presented in support of these claims. A second issue which should be considered before accepting the validity of the proposed relationship is the lack of information on the dietary habits of children not experiencing behavioral or academic problems. A system of accurately recording the dietary intake of normal children is necessary in order to understand the relationship between any food substance and behavior.

Sugar and behavior: controlled studies

Sugar and Intellectual Performance

In contrast to the anecdotal and correlational reports cited above, which have associated sugar consumption with adverse behavioral outcomes such as hyperactivity or learning disabilities, two controlled studies using college students, have investigated the hypothesis that high blood glucose levels would facilitate learning (Longo, 1976; Lapp, 1981).

Based on reports of decreased mental functioning associated with hypoglycemia, Longo, 1976, proposed a relationship between levels of sugar in the blood and intellectual performance. No relationship was found, however, between blood sugar levels, measured by GTT's, and performance on a drawing task used to measure I.Q., the House-Tree-Person task (Buck, 1966).

In contrast, Lapp (1981) found subjects with high blood glucose levels (130 mg./100 c.c. blood) showed significantly superior recall on tests of paired associate learning compared to subjects with low blood glucose levels (80 mg./100 c.c.).

Lapp (1981) suggested the need for further research in this area to clarify the mechanism responsible for these findings.

In particular, whether they could be attributable to changes in serotonin synthesis, as proposed by Wurtman and his associates, or whether poorer performance by the low blood glucose group resulted from distracting factors such as hunger.

Sugar and behavior

To date only three methodologically sophisticated studies

have investigated the proposed relationship between sugar consumption and children's behavior. Of these the initial study was correlational in nature, and did not attempt to manipulate experimentally the amount of sugar consumption (Prinz, Roberts and Hartman, 1980). Food consumption of 28 hyperactive and 26 control children was monitored for one week through daily dietary diaries kept by their parents. There were no significant differences between the two groups in terms of the children's consumption of sugar products or in the ratio of sugar products to other nutritional foodstuffs such as protein or carbohydrate. The hyperactive children, however, are reported to have consumed significantly less total amount of food than the controls. This reduced total food intake amongst the hyperactives could perhaps be attributable to the known anorexic effects of stimulant medication since 15 of the hyperactive children had a history of stimulant medication (Barkley, 1981). An alternative explanation could be that the hyperactive children were unable to sit at a meal table long enough or spent too much time talking to finish consuming their meal.

The authors report a differential response to high levels of sugar intake in hyperactive children as compared with normal children. Significant correlations are reported between high intakes of sucrose and increased agitation and destructive-aggressive behavior amongst hyperactive children, but not with increased motor activity per se. The converse was true for the control group, who displayed increased

motor activity associated with high sucrose intake.

The correlational nature of this study does not establish a cause-and-effect relationship between high levels of sugar consumption and increased destructive-aggressive behavior in hyperactive children. Barkley (1981) has suggested an equally plausible relationship in that poor impulse control amongst more aggressive and restless children may account for an increased sugar intake. Alternatively, Conners, Wells, Horn, Blouin, Beerbohm, O'Donnell, Seidel & Shaw (1982) suggested that the children may have been compensating for the amount of energy expended in increased aggression and restlessness by increasing their consumption of carbohydrates.

Only two studies to date have attempted to clarify the nature of the correlational relationship by an experimental manipulation of sugar consumption. The first study investigated the effects of sucrose and fructose consumption in a group of 12 severely disturbed psychiatric inpatients, aged five to 13 years (Conners et al., 1982). The children received 50 grams of sucrose, fructose or no sugar in orange juice in a modified Latin-square sequence on three different days. "Challenge" days were separated by at least one day to minimize possible carry-over effects. Significant effects of sucrose and fructose consumption are reported on observational measures of total motor activity and inappropriate behavior. No effects were found on a teacher rating scale (Conners Abbreviated Teacher Questionnaire, Conners, 1973). Although Conners does not specify the number of children who responded to the challenge, this study is the first experimental study.

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in which a causal relationship has been demonstrated between sucrose and fructose consumption and increased motor activity and decreased appropriate behavior. These effects, however, were only significant when results from both sucrose and fructose conditions were combined, and may not have been clinically impressive, since they were not reflected in the teacher rating scales. A further caveat which the authors themselves emphasize concerns the applicability of these adverse findings in a group of severely disturbed psychiatric inpatients to sugar consumption amongst normal children.

The second experimental study investigating the effects of sugar consumption on behavior was conducted with twelve normal boys (mean age 10.7 years) selected on the basis of parental belief that their behavior deteriorated after significant sugar intake (Behar, Rapoport, Cornblath & Berg, 1982). A double-blind random assignment of glucose, sucrose or placebo challenges was administered on non-consecutive days. The challenges were given in a lemon flavored ice "slurry" to which saccharin had been added for all conditions. This maintained the double-blind nature of the study by ensuring that the placebo condition could not be distinguished on the basis of saccharin aftertaste. Glucose tolerance tests over a five hour period were carried out simultaneously with behavioral tests of attention, memory, a continuous measure of motor activity, and a behavioral rating scale.

No significant effects were found on any behavioral or cognitive measures or the teacher's rating scale either

when the individual sugars were compared with placebo, or when both sugars were combined. In contrast to the finding of increased motor activity reported by Conners et al. (1982), significantly less activity was recorded on sugar than on placebo (Rapoport, 1982). Whether this apparent contradiction in findings may be attributable to differences in subject population, i.e. psychiatric versus normal, or to differences in the method of measurement, i.e. observational versus the use of an actometer, cannot be determined on the basis of the available data.

Although no significant group differences indicating adverse response to sugar consumption were found in this study, Behar et al. (1982) did find that three children did become more active on sugars than on placebo associated with "worsening on behavior ratings". These subjects are to be the subject of further investigation as a possible subgroup of "sugar responders".

ADDITION INFORMATION

Summary

Present evidence suggests that many children consume vast quantities of sugar as a major portion of their diets. A relationship between high sugar consumption and behavioral effects such as increased disruptive behavior or learning difficulties in school has been accepted as established by many parents and educators. However, the hypothesis that nutritional variables may have direct behavioral effects has only recently been subjected to rigorous scientific investigations. Most behavioral research in this area to date has concentrated on the effects of artificial food additives such as flavors or colors, and, in many cases, less is known about natural food substances than artificial additives (Kolbye, 1982).

A number of possible mechanisms through which sugar consumption could have a direct behavioral effect have been proposed. Of these, two, i.e. functional hypoglycemia and food allergy, are considered by many researchers to be as controversial and poorly defined as the syndromes of hyperactivity or learning disabilities which have been attributed to them. A third proposed mechanism, in terms of alterations in brain neurotransmitter synthesis, appears to offer a more scientific explanation for dietary effects on behavior. Further research, however, is necessary to determine whether brain neurotransmitter synthesis may be altered by dietary variables alone, and, if so, to establish whether such changes have functional significance.

Although only two studies have been conducted to date which have attempted to directly manipulate sugar consumption, relevant research has been conducted on other defined diets used in the treatment of childhood behavior disorders. Three such diets, allergy elimination diets, megavitamin treatment and the Feingold diet frequently entail significant reduction in sugar consumption. In the case of allergy elimination and megavitamin treatments, most of the information is anecdotal. There is however, some limited support implicating the possible role of reduction in sugar intake in behavioral improvements reported in experimental studies of these diets (e.g. Kershner & Hawke, 1978; O'Banion et al., 1978, Rapp, 1978). The Feingold diet has been the subject of most research in this area, and a number of findings have emerged which should be considered in an investigation of the effects of sugar on children's behavior. Firstly, open clinical studies have continued to confirm Feingold's initial claim of improvement in 50% of children placed on the diet (Conners, 1980). Since controlled studies on the effects of food colors have, in general, failed to substantiate Feingold's claims of dramatic behavioral response to these additives, it remains possible that other nutritional variables such as reduction in sugar consumption could be accounting for behavioral improvement noted in clinical trials.

Secondly, a consistent pattern in the results of both diet and challenge studies suggests that there may be a parti-

cular subset of children who do show behavioral responses to food dyes. Furthermore, it appears that this subset of children may be comprised of younger children. For example, Harley et al. 1978 in a placebo controlled double-blind diet crossover study of preschool boys reported that all 10 mothers and four of the seven fathers rated their children's behavior as improved on the Feingold diet. Conners (1980) also reported that two of the "best responders" (of the four out of thirteen children to show an effect) to food dye challenge were 4.5 and 6 years of age. Similarly, Weiss et al. (1982) reported the only dramatic response to food dye challenge in the youngest of 22 children participating in the study (a 34 month old girl). It appears, therefore, that the young child may be particularly susceptible to behavioral effects caused by ingestion of food additives. Research to date has not been conducted to determine whether the increased susceptibility of the young child may also apply to other food substances particularly sugar.

There have been few controlled studies which have experimentally manipulated sugar intake in order to determine whether any cause and effect relationship could be demonstrated between sugar consumption and behavior. These studies have produced the conflicting results familiar to research on nutrition and behavior. Improvement in memory and learning tasks related to high blood glucose levels has been reported in one study by Lapp (1981), but this finding was not replicated by a subsequent

study on the effects of glucose and sucrose by Behar et al. (1982). Similarly, increased total motor activity following sucrose and fructose consumption was reported by Conners et al. (1982) but again not replicated by Behar et al. It is not clear to what extent these differences in findings may be attributed to differences in experimental measures and procedures. For example, in the Behar et al. study the possibility of children evidencing increased motor activity may have been precluded since, as the authors state, "they were not permitted rough play so as not to jeopardize the function of the IV" (Intravenous needle). Differences in the nature of the subject selection, ranging from college students to child psychiatric inpatients may also have contributed to the discrepancies in the results.

A study of the effects of dietary substances on behavior has a number of difficulties associated with the design. Firstly, it may be more difficult to maintain adequate double-blind procedures than in the case of drug research, since the child can see and taste what he consumes. Secondly, previous research in this area, e.g. Rapoport, Elkins, Neims, Zahn & Berg, 1981, has emphasized the need to obtain information regarding the child's dietary history. In their study, on the effects of caffeine, a differential response in self-report ratings of caffeine side-effects is reported between habitual high users of caffeine and caffeine-abstainers.

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Thirdly, the proper selection of measures which are both sufficiently sensitive, and relevant to the hypothesized effects of consumption of dietary substances such as caffeine, sugar or food additives may be difficult.

The use of stimulant medication in the treatment of hyperactive children has been the subject of much research (see Werry, 1978; Barclay, 1980 for reviews of this literature). Measures in studies of the effects of dietary substances on children's behavior have been selected on the basis of those measures which research has shown to be sensitive to the effects of stimulant drugs in hyperactive children. For example, the Conners Parent and Teacher Rating Scales and the Conners Abbreviated Teacher Rating Scale (Conners, 1973) have been used frequently. Evidence suggests, however that the effects of dietary substances on behavior may be more subtle or different from the effects of stimulant medication, and may not be reflected by scores on the Conners rating scales. For example, Rapoport et al. (1981), in the previously cited study of the effects of caffeine, reported no significant differences on the Conners Parent and Teacher Rating Scales between the caffeine and placebo conditions, yet all but two of 19 mothers were able to guess correctly which treatment their child was receiving. A similar finding has been reported in challenge studies of the Feingold diet. In a single case double-blind study, the mother of the child challenged with food dyes was able to identify correctly the condition in eight out of ten trials

(Mattes & Gittleman-Klein, 1978); again no significant differences were reported on the rating scales.

The two sugar challenge studies which have been conducted to date reported no significant differences in teacher ratings of behavior, but no information is provided on whether parents or caretakers could identify the experimental conditions. Weiss (1982) has proposed a target-symptom approach in which the mother herself selects items which she considers most applicable to the behavior of her child, and suggests that this may provide a more sensitive indicator of behavior changes.

It has also been suggested that previous equivocal findings in research on dietary factors and behavior may be attributable to the nature of the tasks employed, such as paired-associate learning, rather than behaviors which might be associated with hyperactivity such as activity level, auditory and visual attention, and fine and gross motor skills (Adams, 1981). The more extensive literature on the effects of stimulant medication on hyperactive children has suggested that measures of complex learning, problem solving and reasoning are not sensitive to drug effects (Barkley, 1981), and that measures of attention, activity level and motor co-ordination have most frequently been reported to show significant effects of stimulant medication (Knights, 1974). However, no one test or battery of psychological assessments has yet been shown to be most sensitive to diet-induced behavioral changes (Wurtman, 1982).

The Present Study

The purpose of the present study was to evaluate the effects of sucrose on the behavior of young, normal pre-school children. The study utilized a double-blind challenge paradigm. Children were administered two placebo and two sucrose conditions on nonconsecutive days. Baseline measurements were taken for two days prior to, and in between, the experimental days. Three types of measures were included in this study: psychometric tests, target symptom checklists, and behavioral observations. Background information included a measure of parental attitude towards nutrition and behavior and a dietary history.

METHOD

Subjects

Eighteen children from the Carleton Preschool participated in this study. None of these children had any known history of allergic reactions to sugar, hypoglycemia or diabetes. Participation in the study was on a voluntary basis. Parents of all of the children attending the preschool were sent a letter informing them of the nature of the study and asked if they would be willing to allow their child to participate. (See Appendix A.) If this was affirmative, parents were contacted individually and the details of the study further explained to them either at a personal interview or by telephone. Parental consent forms were then signed (Appendix B). Twenty-two parents originally expressed an interest in having their child participate in the study. Two children could not be included in the study as they did not drink apple juice at school. One was excluded from the study as he was considerably older than the remaining subjects (6.5 years), and one was excluded due to stressful factors in the child's home.

The subjects, nine boys and nine girls, ranged in age from 3.5 years to 5.3 years, with a mean age of 4.2 years. The Peabody Picture Vocabulary Test (Revised) (Dunn & Dunn, 1981) was administered to the children participating in the study and the mean I.Q. was 112, with a standard deviation of 12.9. All the children were right-handed.

Measurement

A. Background information

- 1) A Nutrition Attitude scale (Appendix C, was developed

to provide some information on maternal attitude toward nutrition and behavior in general, and also the extent to which the mother believed that sugar consumption had a direct effect on her own child's behavior. The Nutrition Attitude Scale is a five point Likkert-type scale, and a score is calculated separately for each of the two sections of the scale.

2) A diet history (Appendix D) adapted from Connors (1980) and Charlton-Seifert, Stratton and Williams (1980) was used in this study. Diet histories have been shown to provide reliable information on the usual food intake pattern of an individual over a relatively long period of time (Mann, Pearson, Gordon & Dawber, 1962). In addition to providing information on the usual food intake pattern of the child, this history also supplied specific information on the child's normal breakfast and information on any particular problems associated with food such as allergies. The diet histories were scored to provide some measurement of general sugar intake. For those items containing a high percentage of sugar, the columns were scored on a scale from 0 to 2, indicating seldom, occasionally, or daily. The parents were not specifically instructed as to which items were used in this scoring system.

B. Psychometric measures

1) Actometers

General activity level was measured by a wrist actometer. These are Timex watches modified to be sensitive to movement, indicated by the movement of the watch hands. The amount of movement was recorded in terms of the total number of seconds moved by the watch hands.

2) Purdue Pegboard

Fine motor co-ordination was assessed by a version of the Purdue Pegboard adapted for use with preschoolers (Wilson, Iacoviello, Wilson & Risucci, 1982). The standard 25-pair Purdue Pegboard Test (PPT) is reduced to 15 pairs (29.5 x 29.5 cm.). Following demonstration and a practice trial, the child was instructed to pick the pegs up one at a time with his right hand and place them in the holes (on the right side of the board) as quickly as possible until told to stop. The score is the number of pegs placed within a 30-sec. time period. This procedure was repeated with the left hand (with the pegs placed in the left side of the board) and bimanually (with the pegs placed on both sides of the board). Normative data on this test is available for preschoolers (Wilson et al. 1982) and the test has been shown sensitive to neurological dysfunction in learning disabled children (Gardner & Broman, 1979).

3) Developmental Drawings

Visual-motor co-ordination was assessed by Developmental Drawings (Knights & Norwood, 1978, Appendix E). This test consists of a series of simple drawings which become progressively more difficult. Normative data on this test is available (Knights & Norwood, 1980). Drawing tests and tests of visual-motor co-ordination have frequently been shown sensitive to brain functioning (Koppitz, 1979) and have also been used in drug studies to show the effects of stimulant medication on hyperactive children (Knights, 1974; Lerer, Lerer & Artner, 1977).

4) Standing on one foot

This task was used as a measure of gross motor coordination and was adapted from a subtest in the McCarthy Scales of Children's Abilities (McCarthy, 1972). The child is requested to stand on the right foot as long as possible. The score is the total number of seconds the child is able to stand on one foot (up to maximum possible score of 30 secs.). The same procedure is repeated with the left foot.

C. Behavior Checklists

1) Target Behavior Checklist (Parent's)

Each mother of the children involved in this study was asked to select a ten item checklist from the 93 items Conners Parent Scale (Appendix F) indicating those behaviors most representative of her child, when he/she was having a "bad day". The target symptom behavior checklist approach has been proposed as a more sensitive instrument in the measurement of subtle behavioral changes associated with diet manipulations than the standardized checklist approach traditionally used in drug studies (Weiss et al., 1982). The checklists were scored according to the original Conners' form with a checkmark placed in one of four columns indicating not at all, just a little, pretty much or very much, scored on a scale of 0 to 3. An example of a checklist is presented in Appendix G.

2) Target Behavior Checklist (Teacher's)

A similar target behavior checklist was selected for each child by the teacher responsible for that child. Ten items were again selected as reflecting behaviors most

characteristic of that particular child on a "bad day", from the 39 item Conners' Teacher Rating Scale (Appendix H). An example of a teacher checklist is presented in Appendix I. 7

D. Behavioral observations

An observational coding system based on that developed by Ballard (1981) was used. A detailed description of the code may be found in Appendix J. This system was chosen since it allowed measurement of the children's behavior with peers and peer responses to them. Measures of verbal and non-verbal interaction, both positive and negative are included also. In addition, the scale comprises the play categories developed by Parten (1932), which have frequently been used in research on child development to evaluate the extent of social involvement in children's play (Ausubel & Sullivan, 1970). An interval time-sampling method of observation was used in which each child was observed for four 15 sec. intervals. The 15 sec. interval allows a meaningful unit for behavioral coding in a free play situation. The grouping of observations on each individual child into sets of four necessitates a change to the next child only after a one minute period (in a free-play setting it is too difficult to search for a new child after each 15 second period). This method still allows sequential time sampling which has been shown to be less subject to error than contiguous sampling across a session (Thomson, Holmberg & Baer, 1978).

A priority coding system as recommended by Ballard was used such that when an interaction occurred during the 15 sec. interval this was recorded and when no interaction occurred the

child's play activity was recorded. Priority coding has been used to record as much as possible of observed behavior and at the same time reduce the number of behavioral categories (Jones, Reid & Patterson, 1974).

The behavioral coding system used in this study consisted of the codes proposed by Ballard, with the exception of the play code for Associative Play (A). Pilot testing indicated that this category seldom, if ever, occurred in the absence of verbal interaction. In addition, it was felt this would reduce confusion and improve inter-rater reliability since the code "A" was also used for any interaction either initiated or received by an adult.

The percentage of the total number of observation periods for each child for each of the nine study days was calculated for the interaction codes and play categories.

Reliability

A research assistant (B.A.Hon.), was hired to establish inter-rater reliability and determine the accuracy of the observation data. Training sessions took place over a one month period prior to the onset of the study. These sessions also allowed the children to become familiar to the presence of observers in the pre-school setting. Inter-observer agreement co-efficients were calculated at the end of this training for interactions, for play categories and total agreement by using the following formula

$$\frac{\text{no. of agreements}}{\text{total no. of agreements plus disagreements}} \times 100$$

Agreement was defined only when both observers recorded the same interaction or the same category for the Parten play codes. Agreement for interaction was scored only when exactly the same interaction occurred, i.e. the same direction of interaction (initiated by the target child or directed toward to the target child), the same type of interaction (verbal or non-verbal), the same quality of interaction (positive or negative), and whether or not an adult was involved in the interaction. This code is complex and agreement is only reached when at least four and sometimes five symbols are coded identically. Agreements in the range of 80% to 85% have been suggested as a realistic upper limit in the use of complex codes (Johnson & Bolstead, 1973; Taplin & Reid, 1973). Inter-rater reliability prior to onset of the study was 85% for interaction codes, 98% for play codes, with an overall inter-rater reliability of 91%.

Reliability observations were carried out at intervals through-out the study period, for each group of children, for 32% of the observation sessions. Inter-rater reliability for interactions ranged from 76% to 92.9%, with a mean of 86.4%. For play categories, agreement coefficients ranged from 81.8% to 100%, with a mean of 91.4%. Overall inter-rater reliability for both interactions and play categories during the study period ranged from 86.9% to 95.8%, with a mean of 89.1%.

Design

The basic design of the study is a double-blind placebo control with two administrations of sucrose and two of aspartame. The sucrose and placebo dosages were given in a pseudo-random order and on non-consecutive days to avoid any possible carry-

over effects. The order of presentation was randomized with the constraint that both the sucrose and aspartame were represented within each of the two pairs of administration (see Appendix K). The study was not conducted on days when sugar was consumed at the preschool, for example, birthday parties or a trip to the sugar bush.

The sequence of administration was prepared by Dr. Ferguson and the solutions prepared by Wanda Stubinski, the histologist of the department of psychology, Carleton University. Both treatment and placebo were given in 100 ml. of apple juice, which naturally contains about 11% fructose, or approximately 11 grms. per serving. Sucrose added to the apple juices was in the amount of 30 grams. This is the equivalent of approximately one slice of non-iced chocolate cake or two chocolate bars. This corresponds to approximately 1.8 grams per kilogram calculated on the basis of the average weight (16.5 Kg.) for a four year old child. A single dosage was utilized in this study to facilitate the double-blind design since children only gain approximately 2 kgs. per year during this age period (Nelson, Vaughan & McKay, 1969). The amount used is similar to the 1.75 grms./kg. used by Behar et al. (1982) and the average dose of 1.88 grms./kg. used by Conners et al. (1982) who gave a standard 50 grms. of sucrose to children aged 5 - 13 years. Aspartame was used as a placebo in this study. It is a non-artificial sweetener consisting of two naturally occurring amino-acids, aspartic acid and phenylalanine, with a methyl radical. The chemical structure

structure of aspartame is illustrated in Figure 8. The aspartame used in this study was provided by the manufacturers, G. D. Searle & Co., Skokie, Illinois. Since aspartame is approximately 180 times as sweet as sugar (Frey, 1980), 167 mg. of aspartame were added to the 100 ml. of apple juice to produce an equivalent amount of sweetening.

Baseline measurements of activity level, observational behavior codes, and parent and teacher ratings were collected on two days prior to the first challenge and on the non-consecutive days between each challenge. Psychometric measures i.e. pegboard, Developmental Drawings and standing on one foot, were collected on the two baseline days prior to challenge and on each of the challenge days for a total of six repeated measures. These data were not collected on the days between challenges since pilot testing had shown that it was virtually impossible to maintain the child's co-operation in performing the same task on nine consecutive days.

Procedure

Parents of all the 40 children attending the preschool were sent a letter informing them of the nature of the study as outlined in a previous section. In addition all the parents were asked to complete the Nutrition Attitude Scale whether or not they wished their child to participate in the study. This information from non-participating parents was collected in order to allow more meaningful interpretation of the attitudes of the parents of the children who participated in the research.

Diet history forms including information on the child's

Figure 8 *

L-Aspartyl-L-phenylalanyl methyl ester (aspartame).

* from Lindley (1979).

normal breakfast were completed by the parents of the children involved, and each parent selected 10 items from the Conners' Parent Questionnaire to form their child's individual target symptom checklist. None of the children participating in the study normally consumed sugar-laden cereal products or high sugar products such as cakes or cookies for breakfast. All the children, according to parental reports, normally consumed a breakfast consisting of a combination of fruits, cereals, eggs or meat and breads (sample breakfasts are illustrated in Appendix I). The parents were asked to maintain their children on their normal breakfast and specifically avoid any excess of sugar products during the study period.

Children in both the morning and afternoon preschool programmes participated in this study in groups of three. The observation coding system of Ballard was originally designed for the observation of three children in each observation session. Moreover, the children at the preschool are normally given their snack in groups of three. Including children in the study in the same group of three who all received the same treatment on each day helped maintain the double-blind nature of the study.

Behavioral observations were coded for a period of approximately 60 minutes of free-play activity following snack-time at 9:45 a.m. or 1:45 p.m. (It was not found possible to extend the period of observation for longer than one hour due to other activities in which the child was involved, such as circle-time, or dressing in snowsuits, etc. in order to go outside in the winter.) Behavioral observations were

collected for each of the nine study days.

Parents were instructed to complete the target behavior checklist on their child for each day in which their child participated in the study. Since the parents were unaware of which days were "challenge" days, they were also asked to guess whether or not their child had received sugar on that particular day. The teacher responsible for the child was also asked to complete the individual target checklist at the end of each session (morning or afternoon). Since the teachers served the apple juice to the children they were aware of which days were treatment days but were "blind" as to whether the treatment was sugar or placebo.

The actometers were placed on the child's wrist each day as soon as they had finished their snack. The psychometric tests were administered approximately one hour after the children had consumed their juice, at which time the actometers were removed and the number of seconds recorded. Testing was carried out in the office of the Director of the Preschool. Each child was tested individually and the total testing time per child was approximately 10 minutes. The pegboard task was administered first as it was considered to be a less demanding task for the children. The drawings task was then administered followed by the standing on one foot.

RESULTS

Statistical analysis

The measures used in this study fall into four categories: i) psychometric measures, ii) behavior checklists, iii) observational data, iv) background information. Statistical analyses of each type of measure were conducted separately.

Analysis of the background information consisted of comparisons between the attitudes of parents of the children participating in the study and those who did not wish their children to participate. In addition, correlational analyses were conducted between the two scores of the Nutrition Attitude Scale, the dietary history and the other experimental measures - i.e. psychometric, rating scales, and observational data.

The experimental design in this study was an entirely within-subjects repeated measured design. The data on each experimental measure could be analyzed using either an univariate or a multivariate approach. In view of the highly restrictive assumptions of homogeneity of treatment difference variances, many authors have recommended a multivariate approach to the analysis of repeated measures data (see Harris, 1975).

The SPSS MANOVA program for repeated measures designs was used for the analysis of the experimental measures. In each case analyses were conducted on the mean score for each of the three conditions - baseline, sugar and placebo.

Data on three of the psychometric tests were collected on

two days for each condition, i.e., two baseline days prior to treatment, two sugar days and two placebo days. Analyses were, therefore, conducted on the mean of the two scores of each condition.

In the case of the remaining variables, actometer scores, behavior checklist scores, and observational data information was available for a total of five baseline days (two pre-treatment and three inter-treatment). Preliminary analyses were, therefore, conducted on the baseline data to determine whether there were significant differences between these baseline days. Analyses of all of the experimental measures, psychometric, behavior checklists, and observational data were also conducted with the sex as a between-groups factor to determine whether there were any sex differences on any of the variables.

) Previous research on dietary variables and behavior, has suggested that only a specific subset of children may be affected by the food they eat. The problem of differences between individuals in response to treatment is familiar to clinical and applied research. Individual responses may not be apparent when analyses are conducted on the basis of group means in which valuable information on intra-individual differences is lost (Knights & Stoddart, 1981). For this reason, data on each child individually were represented graphically to determine whether any child showed a particular pattern of responses to sugar.

Psychometric measures

Multivariate repeated measures of analyses were performed on the scores for each of the psychometric tests.

Actometer scores

A preliminary analysis on actometer scores for the five baseline days (two prior to treatment and three inter-treatment days), found no significant differences between the days. Subsequent analyses of the actometer scores were based on the mean score for the five baseline days and the mean scores for the two sugar and the two placebo days. No significant main effects of treatment (baseline versus sugar versus placebo) were found. Analysis of these scores using sex as a between group factor also resulted in no significant main effect for sex and no significant interaction effects.

A summary of the raw data on the psychometric measures is presented in Table 4. Analyses of the actometer data were based on 17 children since one child refused to wear the actometer after the baseline period.

Pegboard scores

A repeated measures MANOVA was performed on the three scores of the pegboard task (right-hand, left-hand and both-hands). Data on the pegboard were available for 13 children, the remaining five children being unwilling to leave the pre-school situation. The analyses were performed on the mean of the two scores for each condition. No significant main effect was found for treatment. A significant main effect

Table 4

Summary of raw data
Means and Standard Deviations of Psychometric Scores

<u>Tests</u>		<u>Baseline</u>	<u>Sugar</u>	<u>Placebo</u>
<u>Acetometer</u>	Boys (9) ¹	630 (335) ²	602 (423)	474 (124)
	Girls (8)	560 (168)	532 (168)	685 (305)
<u>Legboard</u>	Right-hand Boys (8)	8.3 (1.5)	7.9 (1.0)	8.2 (1.2)
	Right hand Girls (5)	8.3 (1.4)	7.7 (1.8)	8.3 (2.5)
	Left-hand Boys (8)	7.4 (1.8)	7.1 (1.3)	6.9 (1.4)
	Left-hand Girls (5)	8.0 (2.1)	7.0 (2.1)	6.9 (2.2)
	Both hands Boys (8)	4.3 (1.4)	5.1 (1.6)	4.8 (1.1)
	Both hands Girls (5)	5.2 (1.5)	5.9 (1.8)	5.2 (1.2)
<u>Develop- mental Drawings</u>	Boys (4)	9.9 (1.3)	7.6 (2.2)	9.5 (1.1)
	Girls (4)	10.6 (2.6)	9.7 (2.5)	9.3 (2.2)
<u>Standing</u>	Right-foot Boys (5)	5.9 (5.9)	5.0 (2.7)	5.7 (3.0)
	Girls (6)	6.9 (6.9)	7.7 (6.2)	8.2 (4.3)
	Left-foot Boys (5)	3.4 (0.5)	2.8 (0.5)	3.2 (2.3)
	Girls (6)	6.6 (2.4)	7.8 (5.4)	5.7 (1.8)

- 1 - number of subjects
2 - standard deviations

for hand was found ($F = 166$; $df = 2, 11$; $p < .001$). Subjects performed best with their right hands, slightly worse with the left hand, and experienced the most difficulty in the both hand condition. A significant interaction between hand and treatment was found ($F = 4.9$; $df = 4, 9$; $p < .05$). Univariate F-tests of the specific contrasts involved in the interaction showed that this significant interaction was the result of differences in the baseline condition in which there was a greater difference between the score for the both-hand task and the mean of the right and left hand scores than at the other treatment levels ($F = 16.26$; $df = 1, 12$; $p < .005$). This interaction is displayed graphically in Figure 4. Analyses of scores on this task using sex as a between group variable showed no significant effect of sex.

Developmental Drawings

Since the scoring of the Developmental Drawings is somewhat subjective, drawings from three of the children were re-scored by a trained psychometrist at the Children's Hospital of Eastern Ontario familiar with the test. The psychometrist was "blind" as to the condition (baseline, sugar, or placebo) and was also unaware that the set of 18 drawings represented the performance of only three subjects tested at six different times. Inter-rater reliability was calculated according to the formula

$$\frac{\text{no. of agreements}}{\text{no. of agreements plus no. of disagreements}} \times 100.$$

This resulted in an agreement coefficient of 86%.

DRAWING SCORES

PEGBOARD SCORES

FIGURE 9

A repeated measure Manova was performed on the mean scores for each condition on the Developmental Drawings test. Data on this test were only available for eight subjects. The task was found to be too difficult for six of the subjects who had performed the pegboard task. A significant main effect of treatment was found ($F = 7.0$; $df = 2, 6$; $p < .05$). A univariate F test of the specific comparisons showed a significant difference between the sugar and the baseline and placebo conditions ($F = 6.7$; $df = 1, 7$; $p < .05$). These data are presented in graphic form in Figure 10. No significant main effect or interaction effect of sex was found in an analysis using sex as a between group factor.

Standing scores

A repeated measures Manova was performed on the mean scores for each condition on the results of the standing on one foot task, for both the right and left foot. No significant main effects for condition or for foot were found, nor was the interaction significant. Data on this task were available for 11 children.

Correlational analyses

Correlational analyses on the psychometric variables is presented in Table 5. Significant relationships were found between the three pegboard scores ($p < .001$). In addition, a significant correlation was found between the pegboard scores and the Developmental Drawing score. No significant relationship was found between the scores on these two tests and on the standing on one foot test.

Text complete, but 82 omitted in numbering.

TABLE 5

I.Q.	right pegboard	left pegboard	both pegboard	right standing	left standing	Drawings	
I.Q.	--	.41*	.37	.25	.14	.05	.56*
right pegboard	--	.85***	.83***	.49*	.41*		.63**
left pegboard		--	.92***	.37	.33		.68**
both pegboard			--	.49*	.50*		.73**
right standing				--	.63**		.57*
left standing					--		.48*
Drawings						--	

* p < .10

** p < .05

*** p < .001

No significant relationships were found between scores on the psychometric tests and the IPVT(R), although there was a trend ($p < .10$) toward a significant correlation between I.Q. and scores on the right-hand pegboard ($r = .41$), and on the Developmental Drawings ($r = .56$). Since the IPVT(R) only measures receptive language functioning and the psychometric tests used were essentially visual-motor tasks, this result is not surprising.

Behavior checklists

Preliminary analyses of the baseline data showed no significant differences between the pre-treatment and inter-treatment days for either parent or teacher checklists. Analyses of the mean scores for each of the three conditions also showed no significant main effect of condition on either measure. Data on the teachers target behavior checklist were available on 17 of the 18 children, and on the parent's checklist for 15 of the 18 children. Means and standard deviations of this analysis are presented in Appendix M.

A Pearson product moment correlation was also performed on the scores on the Parents' checklist with the scores on the teachers' checklist. No significant relationship was found between the two scores.

Of the fifteen parents who completed the target symptom checklists, and checked whether or not they thought that their child had received sugar that day, 47% checked "don't know" on each study day. A chi-square analysis was conducted on the replies

of the remaining parents frequency of correctly versus incorrectly guessing that their child had received sugar that day and showed no significant difference.

Observational behavior codes

Of the 15 codes in the Ballard system used in this study, a number of codes were scored too infrequently to allow meaningful analysis with parametric statistics.

The children in this particular preschool sample spent a large proportion of their time in verbal interactions. The average percentage of time spent in child initiated positive interactions was 29.4%, and the average percentage time in which the target child received a verbal positive interaction was 23.4%. Thus the total amount of time spent in verbal interactions was 52.8%. This pattern of high verbal activity resulted in a very low incidence of other interaction codes which were only coded in the absence of verbal interaction. For example, the interaction code, G, denoting "sharing" is only scored when this occurs in the absence of verbal interaction on the part of either child involved in the interaction. This occurred too infrequently

in this sample to warrant the inclusion of this code in any further analysis. Similarly, the codes, MG $\rightarrow$ + and MG $\leftarrow$ + indicating a motor-gestural movement of affectionate physical contact (hug, hold hands) seldom occurred in the absence of any verbal interaction and were also not included in any further analyses. While the codes for negative verbal and non-verbal interactions were scored very infrequently, they were considered to be of theoretical relevance to the hypothesised effects of sugar on behavior. Since the low frequency of occurrence resulted in highly skewed distributions, a non-parametric analysis was conducted separately on a negative behavior code representing total child-initiated negative behavior derived from both verbal and non-verbal codes.

The interaction code representing interactions either initiated by an adult or responded to by an adult was the only remaining interaction code which was scored sufficiently frequently to allow meaningful analysis (accounting for 17.9% of the observations).

Given the high rate of verbal interaction of these children and the method of priority coding used in this study in which a play code was only coded in the absence of an interaction, low frequencies of occurrence of play codes were found. The five play codes were therefore collapsed into two logically meaningful codes: an interactive play code in which the child was actively involved in a play situation with at least one other child (i.e. the Parallel

and Co-operative codes) and a non-interactive play code in which the child was either playing alone or was essentially unoccupied (i.e. the Solitary, Unoccupied and Onlooker codes).

A repeated measures Manova analysis was therefore conducted on a total of five codes: three interaction and two play codes (child-initiated positive verbal interaction, peer-initiated positive verbal interaction, adult interaction, interactive play and non-interactive play). Observational data was available for the entire 18 subjects and means and standard deviations for this analysis are presented in Appendix N. A significant main effect of code was found ($F = 6.27$; $df = 4, 14$; $p < .005$) indicating a higher frequency of verbal interactions. There was no significant main effect of condition, nor was the condition by code interaction significant. No significant main effects of sex or two-way or three-way interaction effects were found in a subsequent analysis using sex as a between group variable. The derived code for negative behavior was analyzed using Friedman's Two-Way Analysis of Variance (Siegal, 1956). No significant effects of treatment were found.

Pearson product moment correlations between I.Q. scores on the Teacher checklists and the observational behavior codes showed no significant relationships.

Background Information

Two "t" tests were performed on the two scores (general attitude and belief concerning sugar and their child) of the Nutrition Attitude Scale, between those parents who agreed to allow their child to participate in the study and those who did not. There were no significant differences between the two groups on either the general attitude score or the score reflecting belief concerning the effects of sugar on their own child.

A number of parents did not complete the second part of the scale concerning the effects of sugar on their child's behavior as they felt unable to do so since their children did not consume sugar on a regular basis. A χ^2 analysis was performed to determine whether there were significant differences in the frequency of this event between the two groups (i.e. those who agreed to allow their child to participate and those who refused). The results of this analysis were non-significant.

In addition, a Pearson product moment correlation was performed between the two scores of the Nutrition Attitude Scale. No significant relationship was found between these two scores ($r = .08$), indicating that although many parents felt that there was a relationship between nutrition and behavior, they did not feel that sugar had any direct observable effect on their own child.

Pearson product moment correlations were also performed

the study also held this view. No parent of those who completed the nutritional attitude questionnaire disagreed with the above statement and only 9.0% of the parents whose children participated in the study and 6.0% of those who did not want their child included in the study were "undecided" on this issue. This illustrates the phenomenal extent of the belief that nutrition can have a direct effect on behavior amongst this particular group of highly educated parents.

A high percentage of agreement with the statement that the consumption of large amounts of candies such as at Hallowe'en makes some children very excitable was also found in all the parents who completed the nutritional questionnaire. Of those who agreed to allow their child to be included in the study, 59% agreed with this statement, as did 44% of the parents who did not wish their child included. Once again there were no parents in either group who disagreed with this statement, although some parents pointed out that factors other than a reaction to sugar could contribute to increased levels of excitement at Hallowe'en.

Despite this general acceptance that nutrition has an effect on behavior and of the "Hallowe'en effect" very few parents reported behavioral effects of increased sugar consumption on their own child. Anecdotal comments by the parents provided two reasons for this apparent discrepancy. A number of parents commented that their children normally consumed very little sugar and others suggested that they had never looked for any correlation between sugar and behavior in their own children.

between scores on the diet history indicating the extent to which the child normally consumed sugar-laden foods and the psychometric, behavior checklists and observational codes data. The only significant relationship in this correlational analysis was between the amount of sugar normally consumed and scores on the actometer on sugar days ($r = .48, p < .05$). This finding indicates a positive relationship between the amount of sugar consumed and a higher level of activity on sugar challenge days.

Individual data plots

Data for the psychometric measures, the teacher and parent checklists, and the observational coding system were plotted graphically to determine whether there were any relationships between these variables and sugar challenge on an individual basis. Individual data plots confirmed the results of the group analysis of the Developmental Drawing data. The significant group effect appears to be mainly attributable to three of the eight children who completed this task. Graphs of these three "responders" are presented in Figure 11. These may be contrasted with three "non-responders" illustrated in Figure 12.

No consistent pattern of responses was observable on any of the remaining variables, with the possible exception of the actometer scores. Two children showed a marked decrease in activity on sugar challenge days as compared with baseline and placebo days. This pattern was also evident in a third child. Unfortunately, this third child

FIGURE 11

DRAWING SCORES

FIGURE 12

was the only child in the study who refused to drink the juice containing sugar on the second challenge day. The day by day pattern of actometer scores for these three children is presented in Appendix O. The mean score data for each condition of these three children are illustrated in Figure 13, and contrasted with "non-responders" in Figure 14. The three children who showed a response on the Developmental Drawings task were not the same children as those who appeared to show a response on the actometer scores.

ACTOMETER SCORES (seconds)

FIGURE 13

FIGURE 14

DISCUSSION

Relevance of the present findings

The overall findings of the present study have revealed no dramatic effects of sugar on the behavior of young children. Only one of the eleven measures, Developmental Drawings, showed a significant effect of sugar, and analysis of the data on an individual basis suggests that this finding is largely accounted for by only three of the children. This pattern of generally negative results with significant findings on only certain tasks and with only a certain subset of the children involved in the study is consistent with previous research on the effects of dietary variables on behavior (e.g. Conners, 1980; Swanson & Kinsbourne, 1980; Weiss et al., 1981).

The performance of three of the children on the drawing test shows a marked deterioration in visual-motor co-ordination one hour after sugar consumption. It is difficult to relate this finding directly to previous research on the effects of sugar on children's behavior since other studies have not included measures of visual-motor co-ordination. Research on the Feingold diet, however, has shown a similar effect in a more complex visual-motor task one hour after challenge with 13 mg. of food dyes (Conners, 1980). The visual-motor task in Conners' study, known as ZITA (Zero Input Tracking Apparatus), required the child to keep a spot of light on a moving target while simultaneously responding to intermittent flashing lights. Deterioration in performance was not found when the children were retested at intervals of

two and three hours after active challenges. This finding has been interpreted as indicating that artificial food colorings might cause only transient short-term effects. This hypothesis is supported by other findings of short-term effects in research on the effects of food dyes (Swanson & Kinsbourne, 1980). Whether the effect of sugar demonstrated in the present study represents a similar transient effect cannot be determined from the results of this study. Anecdotal reports of sugar and behavior have suggested that effects are immediate and short-lived (O'Banion et al., 1978). The lack of significant findings on parental behavior checklists in the present study could be interpreted as providing evidence for the transient nature of any possible effects of sugar. However, alternative interpretations of this lack of significance appear equally plausible. For instance, changes in visual-motor behavior may be too subtle to create any meaningful changes in the child's behavior that would be apparent to the child's parents.

The analyses of the psychometric measures resulted in only one other statistically significant finding. A significant interaction was found on the Pegboard task between hand and treatment. A greater difference between the scores for the both-hand task and the scores for right and left hands was found at the baseline condition than at the sugar or placebo conditions. There were no differences between sugar and placebo treatments (see Figure 9). The both-hand task is considerably more difficult for the children to perform.

and the difference between the baseline condition and the sugar and placebo conditions is considered to represent a learning effect on this more difficult task. Learning effects are not evident in the less demanding tasks using the right or left hands due to ceiling effects.

No significant group effects of sugar or actometer scores were found, although a distinct pattern of decreased activity level on sugar as compared with baseline or placebo was apparent in individual data plots in three of the 17 children. Large inter-individual differences were found on this task with scores ranging from 140 to 1547. Such large between subjects differences may account for a lack of significant findings in the overall group analysis, despite an apparent effect on three of the children.

The results of the overall analysis of actometer scores do not support the findings of a previous study on the effects of sugar on children's activity level which reported increased activity levels as measured by an observational coding system (Conners et al., 1981). The decreased activity level on sugar days evidenced by three of the children is consistent with findings of decreased activity level on sugar days reported in the Behar et al. (1982) study. The discrepancy in findings between the Conners et al. and the Behar et al. studies may be attributed to differences in method of measurement (observational scale versus actometer) and differences in subject population (psychiatric versus normal). The design of the present study is more similar to

the Behar et al. than the Conners et al. study in the use of actometers and normal children. The current study differs from Behar et al. in that a much younger sample of children was used (mean age 4.3 years versus 10.7 years).

The remaining psychometric test, standing on one foot, showed no significant effects of sugar either in statistical analyses or in examination of the scores on an individual basis. Large individual differences in ability to perform this task were found, with scores ranging from 3.0 secs. to 20 secs. This task was very difficult for many of the children to perform at all.

No significant effects of sugar were found on either parental or teacher behavior checklists. It is possible that this may, in part, be a reflection of this particular pre-school population. The children were not selected on the basis of any behavior problems, and very little inappropriate or disruptive behavior was displayed by any of the children in this pre-school. This factor was particularly evident in teacher ratings of behavior scores which were consistently low. Parental checklists while showing somewhat higher scores and more fluctuation in day-to-day behavior did not reveal any relationship with whether or not the child had received sugar on any particular day. Similarly, the parents were unable to guess correctly whether their child had received sugar that day.

A number of parents added anecdotal comments to the daily target symptom checklists. These comments, e.g. "appears

to be coming down with flu", "was up late last night", etc., suggest that other factors in the child's life may have a more direct effect on the young child's behavior than any subtle effects associated with sugar consumption.

No significant effects of sugar on teacher ratings of behavior were found in the two previously cited sugar studies, although Conners et al. (1981) reported significant decreases in amount of appropriate behavior on sugar challenge days using a behavioral observation scale. This is interpreted as indicative of more subtle behavioral effects than measured by rating scales. Results of the observation coding system in this study failed to show any significant effects of sugar on the children's behavior. This lack of effect on the observation coding system may again be indicative of the nature of the preschool sample used in this study, in which very little inappropriate behavior is evident. This must be contrasted with the subject population in the Conners et al. study of child psychiatric inpatients. A further difference between the present study and that of Conners et al., which may account for the discrepancy in findings, concerns the setting in which the studies were conducted. Conners et al. conducted their observations in a highly-structured classroom situation. Appropriate behavior in this situation was defined as when the child was engaged in an "on-task activity". The free-play setting of the pre-school does not require the child to engage in on-task activity and there are much fewer restrictions placed on the physical activity of the child.

As mentioned previously, children in this particular pre-school engaged in verbal interactions for a large percentage of the time. Many of these children came from professional homes where verbal skills are highly valued. This is reflected by the above average I.Q. Nevertheless, it should be emphasized that no aspect of behavior measured by the observation schedule showed a relationship with sugar.

Individual analysis of the observational coding system data in the present study showed unique individual patterns of behavior. For example, some children spent a considerable amount of time engaged in interactions with adults, while others were more involved in peer interactions. Some day-to-day variation occurred in the amount of adult interaction but was not related to sugar challenge. Other factors in the preschool such as the number of adults in the setting (which was sometimes increased by the presence of students) had a more direct effect on day-to-day variation in this variable.

Day-to-day variations in other aspects of the children's behavior again may be accounted for by more direct factors than any tenuous behavioral effects associated with sugar consumption. For example, increased activity level appeared to result if the children were unable to play outside for an extended period of time due to inclement weather. Other factors such as the day of the week appeared important - children in a school setting are generally more excitable on

Friday afternoon than on a Monday morning.

Analyses of background information, i.e. attitudes toward nutrition and dietary history, produced some interesting findings. Only one significant correlation was found in analyses between these variables and the experimental data. A significant relationship was found between the amount of sugar normally consumed and level of activity (measured by actometer scores) on sugar challenge days. Two of the three children who showed decreased activity on these days normally consumed the least amount of sugar according to parental reports on the dietary history questionnaire. A differential response to dietary substances related to the amount normally consumed in the diet has been reported previously in a study on the effects of caffeine consumption in normal grade school children (Rapoport et al., 1981). Whether differences in the effects of sugar between habitual high and low consumers may be attributed to tolerance effects has yet to be determined; but suggests the need for more epidemiological research on dietary patterns of young children.

One of the most interesting findings of the analyses of the nutritional attitude questionnaire was the extent of the belief that nutritional factors could affect behavior (see Appendix P). Of the parents who agreed to allow their child to participate in the study, 91% believed that "the food we eat can affect the way we feel and behave" (columns either strongly agree or agree were checked). Ninety-four percent of those who did not wish their child included in

the study also held this view. No parent of those who completed the nutritional attitude questionnaire disagreed with the above statement and only 9.0% of the parents whose children participated in the study and 6.0% of those who did not want their child included in the study were "undecided" on this issue. This illustrates the phenomenal extent of the belief that nutrition can have a direct effect on behavior amongst this particular group of highly educated parents.

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Theoretical Issues

The present study although failing to provide support for dramatic effects of sugar consumption did produce two interesting findings, namely a significant effect on a visual-motor task and decreased activity level amongst a subset of the children involved. These results will be considered in light of the mechanisms which have been proposed to account for a behavioral effect of sugar.

Of the three proposed mechanisms discussed in this paper, the hypothesis that adverse behavioral reactions to sugar may be accounted for on an allergic basis appears to have the most disadvantages as an acceptable explanation. Firstly, not only the diagnosis but also the very existence of food allergy has been seriously questioned by medical specialists (Bock, 1980; May, 1975; Tuft, 1973). If an individual has a reaction to a particular food this is normally associated with gastro-intestinal or respiratory tract symptoms. Mood changes associated with specific physical discomfort may be reported, but there is little evidence to suggest that behavioral manifestations may occur "as the sole symptom of adverse reactions" (Bock, 1980). None of the children in this study exhibited gastrointestinal or respiratory tract symptoms and no adverse physical reactions were noted by the teachers or parents.

A second factor arguing against a proposed allergic response to sugar is related to reports of differential sensitivity to cane or beet sugar. Sugar is virtually unique among foodstuffs in that it is a very pure organic compound. The chemical structure of commercial white sugar

is identical whether it is produced from sugar-cane or sugar-beet. International standards for sugar production are controlled by the International Commission for Uniform Methods of Sugar Analysis (ICUMSA), and commercial sugar is estimated to be 99.9% pure with the main impurity being water (Dutton, 1979). The possibility of a differential response to any remaining impurities from cane or beet appears, therefore, extremely unlikely.

In evaluating the significance of the findings of the present study in terms of the hypothesized relationship between hypoglycemia and behavior, a number of problems arise. The controversial issue related to the diagnosis of hypoglycemia has been discussed previously. A second difficulty exists, however, in the lack of specificity of the mechanism through which low blood sugar could have direct behavioral effects. Despite a wealth of popular literature on this subject (e.g. Abrahamson & Pezet, 1951; Bonnet & Pfeiffer, 1978; Lester, 1980; Schauss, 1981; Starenkyj, 1981), it is not clear how alterations in blood sugar levels particularly decreases below the normal fasting blood sugar level, are responsible for the variety of behavioral symptoms which have been associated with this disorder. The general consensus, although often not stated explicitly, suggests that behavioral effects of hypoglycemia are due to decreased availability of glucose to the brain. This is presumed to have a significant effect since the brain not only requires a continuous supply of glucose but is unable to store it in

any form. The decrease in glucose availability is, therefore, claimed to affect the brain's ability to use oxygen associated with such symptoms as faintness and confusion. The number of symptoms which have been associated with hypoglycemia, however, often includes symptoms not usually associated with lack of oxygen such as fatigue, irritability, anxiety, depression, crying spells, dizziness, insomnia, poor concentration, headaches, phobias, destructive outbursts, heart palpitations, muscle cramps, convulsions, low sex drive, and blurred vision (Bonnet & Pfeiffer, 1978). None of these effects were reported by the children or their parents in this study.

An alternative explanation of the hypothesized relationship between low blood sugar and behavior is related to mechanisms involved in the regulation of blood glucose. When the blood glucose level falls below normal, the adrenal medulla is stimulated by the sympathetic nervous system to release both norepinephrine and epinephrine. Epinephrine, in particular but also norepinephrine facilitate the breakdown of glycogen, stored in the liver, into glucose which enters the blood stream to restore blood glucose levels to their normal level (Beck, 1971). Behavioral effects could, therefore, possibly be attributed to increased levels of norepinephrine and epinephrine. However, the relationship between blood levels of these

substances and levels within the CNS is very complex, due not only to the blood brain barrier but also the availability of specific enzymes involved in the synthesis of the neurotransmitters such as phenylethanolamine-N-methyl transferase (PNMT) which is responsible for the methylation of norepinephrine to form epinephrine. This complex relationship must be better understood before accepting the hypothesised relationship between behavioral changes and increased levels of norepinephrine and epinephrine. Furthermore the functional significance of any increased levels of specific neurotransmitters is still not clear. For example, the catecholamines have been shown to be implicated in motor function, although it is thought that dopamine may play a more important role than norepinephrine (Seiden & Dykstra, 1977). The findings of impairment in performance in visual-motor task could possibly be attributed to increased epinephrine and norepinephrine. However, since the present study did not include GTT measures, it is not known whether any of the three children who appeared to show a reaction to sugar on this task had abnormal blood sugar levels. The study of Behar et al. (1981) found no incidence of abnormal glucose tolerance test values for the children in their study, and reported that on sugar challenge days the great majority of children had a transient rise in blood sugar and a return to baseline values within one hour.

The third hypothesised mechanism to account for behavioral reactions to sugar, that of alterations in availability of dietary precursors of specific neurotransmitters, is, perhaps, the most difficult to evaluate. The major disadvantage with the hypothesis that food components may change neurotransmitter synthesis and thence behavior is in the length of the presumed chain of causality (Leathwood & Pollet, 1982). That is, it is proposed that the consumption of a high carbohydrate meal causes changes in the ratio of plasma tryptophan to other large neutral amino acids (LNAA) which changes the rate of tryptophan transport into the brain. This in turn would change the rate of serotonin synthesis and finally result in functional changes. There are two major difficulties associated with this hypothesised chain of events. Firstly, in the biochemical measurement of total brain tryptophan or serotonin, and secondly, in the interpretation of the functional significance of changes in the level of one specific neurotransmitter. As Seiden & Dystra (1977) point out "It is usually impossible to attribute a behavioral effect to one endogenous compound."

A functional relationship between serotonin levels and behavior has been shown in animals using either lesions in the medial forebrain bundle to decrease serotonin levels or drugs such as reserpine to deplete serotonin.

The main behavioral effects shown in this research have been increased sensitivity to pain and changes in sleep patterns (Seiden & Dystra, 1977). The effects of increased sensitivity to pain has been replicated using dietary interventions, in which the animal is fed a tryptophan poor diet (corn) to reduce serotonin synthesis (Lytle et al., 1975), and decreased sleep latencies have been demonstrated in adult humans given four grams of tryptophan (Hartman, 1982). Mood changes consisting of increased drowsiness, and decreased vigor have also been reported in humans given 50 mg/kg of tryptophan (Lieberman et al., 1982). The above findings, therefore, provide some support for the behavioral changes associated with dietary-induced increased serotonin synthesis. The finding of decreased activity level subsequent to sugar challenge reported by Behar et al. (1981) and evident in three of the eighteen children in the present study appears consistent with this model.

However, differences in methodology between the experimental studies cited above and both the present study and the Behar et al. study must be considered. Animals in these studies have been kept in very controlled environments and fed diets of specific amino acid mixes (Chiel & Wurtman, 1981; Lytle et al., 1975). Behavioral effects in humans have been shown following oral dosages of tryptophan (Hartman, 1982; Leathwood et al., 1982). The issue of whether diet alone can effect human behavior is more controversial. Leathwood et al.

(1982) have suggested that the consumption of a single meal produces negligible changes in the plasma tryptophan to LNAA ratio whereas, Wurtman (1982) has proposed that as little as six grams of carbohydrate are sufficient to change this ratio and hence affect neurotransmitter levels. This controversial issue must be resolved before we can accept the hypothesized relationship between dietary precursor availability and neuro-transmitter synthesis. It seems unlikely, however, that a solution to this controversy will be readily available given the difficulties of maintaining either adults or children on strictly controlled diets or accurately measuring brain tryptophan and serotonin levels in vivo.

General overview

The overall findings of the present study do not support the hypothesis that sugar causes a clinically meaningful change in the behavior of young children. Other factors in the child's life, such as amount of sleep or social interactions in the family situation may be more significant in accounting for day-to-day variability in behavior than the consumption of sugar.

The findings of a significant effect on a visual-motor task and the suggestion of decreased activity level in specific subsets of the children are interesting and may be important in determining the nature of the mechanism through which sugar may have behavioral effects. The data from this study appear

to provide limited support for two of the models discussed in this paper. Since the children who showed a response on the visual-motor task were different from those who showed decreased activity levels, it is possible that different mechanisms may be involved in different individuals. This is consistent with the correlational study of Prinz et al. who reported that sucrose consumption may have a different effect on hyperactive versus control children, and that "sugar-laden diets may affect individual children in different ways."

A possible explanation of differential responses to sugar could be in terms of different patterns of normal consumption. The significant correlation between amount of sugar consumed and scores on the actometer, in which decreased activity on sugar challenge days was associated with low sucrose consumption, supports this hypothesis. Further epidemiological work is necessary in this area to provide more information on the normal dietary habits of young children.

The present study has shown behavioral effects of sugar on a visual-motor task and suggested that overall activity level may be affected in a limited number of children. No behavioral effects were evident on an observational behavioral coding system or parent or teacher behavioral checklists. These somewhat contradictory findings emphasize the subtle nature of any behavioral effects

attributable to sugar. This raises the ethical issue of whether a child should be placed on a sugar-restricted diet. Such a diet, as is the case with the Feingold diet, may well have serious social consequences for the child if he can no longer participate in activities such as birthday parties or share in childhood treats such as candy or ice-cream.

The long-term impact of placing a child on a special diet and hence labelling him as different and eliminating him from a variety of social activities with his peers is as yet unknown. However, such potential effects must be evaluated before placing large numbers of children on special diets which are unlikely in themselves to produce any real changes in behavior.

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APPENDIX A

Carleton University
Ottawa, Canada K1S 5B6

Dear Parent:

I am planning to begin a study in the Carleton Preschool to investigate the effects of sugar on children's behaviour. Many of you may be aware of a theory that the consumption of large amounts of sugar has an adverse effect on the behaviour of young children. To date there has been no published scientific study to confirm this theory. As a parent of two boys whose mood and behaviour varies substantially from day to day, the theory of a relationship between diet and behaviour appears worthy of further investigation.

The study which I am planning to conduct for my Ph.D. thesis includes the administration of either sugar (30 grams) or placebo (Aspartame) in the children's juice given at snack-time. Neither myself, nor the teachers involved will know on which day the child receives the sugar. The reason that Aspartame is used in addition to sugar is to be certain that the children and adults concerned cannot tell, on the basis of taste, which day is the sugar day. The amount of sugar is equivalent to that contained in one slice of un-iced chocolate cake or one bowl of cereal with 1 teaspoon of sugar. Aspartame has been rigorously tested in both Canada and the U.S.A. and has been approved for use in both countries as a sugar substitute, for example, in diet soft drinks.

During the ten day study period the children's behaviour at school will be observed and recorded. In addition, I will ask the parents and teachers to complete a short checklist of behaviours on that particular day. On each study day the child will also be asked to perform a few tasks of motor co-ordination, (hopping on one foot, drawing a few simple line figures and a pegboard task). The child will also be requested to wear a modified Timex watch which detects movement.

The proposed study has been approved by the Board of Directors of the Carleton Preschool. I would very much appreciate your co-operation in the completion of this study.

Please indicate on the attached page whether you would be willing to have your child participate in this study. If you do not wish to have your child included in this study, I would still greatly appreciate it if you would complete the attached questionnaire, so that I may gain further information on your attitudes towards nutrition and behaviour.

... 2

APPENDIX A

... 2

Thank you for your co-operation in this study. If you wish any further information I would be pleased to talk to you; Work phone no. - 231-5587 (leave a message on answering machine for Dr. Knights); at home 233-8525 any-time after 3:30 p.m. or leave a message with Marion Barnett at the pre-school. If you do indicate that you would be willing to have your child participate in the study I would like to talk with you personally in order to explain the nature of the study in greater detail.

Yours faithfully,

Clare Stoddart.

Clare Stoddart, M.A.
Ph.D Student
Carleton University
Ottawa

Marion Barnett
Director,
Carleton Preschool

APPENDIX A

I am interested in having my child participate in the study on the effects of sugar on children's behaviour. I understand that I will be contacted personally by Clare Stoddart prior to the study at which time she will explain the details of the study to me in greater detail.

signature

APPENDIX B

Carleton University
Ottawa, Canada K1S 5B6

I hereby give my consent to allow my child, _____,
to participate in the study on the effects of sugar on children's
behaviour. The details of the study have been explained to me and
I feel I have an adequate understanding of the procedures involved.
I understand that participation in the study is on a purely voluntary
basis, and will have no effect on his/her progress in the preschool.

signature

APPENDIX C

MATERNAL ATTITUDES TOWARDS NUTRITION AND BEHAVIOUR

This questionnaire is designed to provide some measure of your attitude towards nutrition and behaviour. Please circle the appropriate number indicating the extent to which you agree with the following statements.

- 1 = strongly agree
- 2 = agree
- 3 = undecided
- 4 = disagree
- 5 = strongly disagree

1) The food that we eat can affect the way we feel and behave.	1	2	3	4	5
2) Specific diets and vitamin supplements can provide alternatives to medication in the treatment of stress.	1	2	3	4	5
3) Health foods and natural foods without preservatives are better for your physical and mental health.	1	2	3	4	5
4) Hyperactivity in children is caused by food additives.	1	2	3	4	5
5) Junk foods eaten by children may affect their ability to learn in school.	1	2	3	4	5
6) The consumption of large amounts of candies, such as at Hallowe'en, makes some children very excitable and hard to handle.	1	2	3	4	5

Answer the following questions as they apply to your own child, _____.

When _____ eats a lot of sugar (e.g. candies, cookies, cakes, soft drinks), _____

a) does not behave any differently from usual.	1	2	3	4	5
b) has a hard time falling asleep at night.	1	2	3	4	5
c) becomes very irritable and easily upset.	1	2	3	4	5
d) becomes very tired and listless.	1	2	3	4	5
e) becomes really "wild" and excitable.	1	2	3	4	5
f) becomes withdrawn and daydreams.	1	2	3	4	5
g) has headaches or stomachaches.	1	2	3	4	5

SIGNATURE

APPENDIX D

DIETARY HISTORY

Name _____ Age _____ Date _____

1) Usual meal times _____
(Sunday _____)

2) Between meal time: A.M. _____ P.M. _____ Before bed _____
Usually what? _____

3) Appetite: Good _____ Varies _____ Poor _____

4) Food likes (10) _____

5) Food dislikes _____
Will he/she try them? _____

6) Problems at meal (table with child) _____

7) Any medical complications with food? _____

8) What is his/her normal breakfast?

APPENDIX D

... 2

Please read the following items carefully and place a check mark on the appropriate line as they apply to _____.

<u>FREQUENCY OF FOOD</u>	<u>DAILY</u>	<u>OCCASIONALLY</u>	<u>SELDOM</u>
Milk	_____	_____	_____
Cheese	_____	_____	_____
* Ice cream	_____	_____	_____
Cereal (hot or cold)	_____	_____	_____
* Sweet rolls or donuts	_____	_____	_____
Sandwiches	_____	_____	_____
Fruit	_____	_____	_____
Fruit juice	_____	_____	_____
Peanut butter	_____	_____	_____
Nuts	_____	_____	_____
Dried peas or beans	_____	_____	_____
Meat in casseroles	_____	_____	_____
Vegetables	_____	_____	_____
Potatoes, rice or noodles	_____	_____	_____
* Cookies or crackers	_____	_____	_____
* Pie, cake or brownies	_____	_____	_____
Potato chips or corn chips	_____	_____	_____
* Candy	_____	_____	_____
* Soft drinks	_____	_____	_____
* Sugared drinks	_____	_____	_____

(* items containing high amounts of sugar)

APPENDIX E

A handwritten signature or scribble located in the bottom-right area of the page.

APPENDIX E

7

DEVELOPMENTAL DRAWINGS

Name _____

CA _____

Examiner _____

Total Score _____

APPENDIX F

CONNERS PARENT'S QUESTIONNAIRE

Name of Child _____

Date _____

Your Name _____

Relationship _____

Instructions: Listed below are items concerning children's behaviour or the problems they sometimes have. Read each item carefully and decide how much you think your child has been bothered by this problem *during the past month* -

NOT AT ALL, JUST A LITTLE, PRETTY MUCH or VERY MUCH

Indicate your choice by placing a check mark (✓) in the appropriate column to the right of each item.

ANSWER ALL ITEMS

Observation	Not at All	Just a little	Pretty Much	Very much
PROBLEMS OF EATING				
1. Picky and finicky				
2. Will not eat enough				
3. Overweight				
PROBLEMS OF SLEEP				
4. Restless				
5. Nightmares				
6. Awakens at night				
7. Cannot fall asleep				
FEAR AND WORRIES				
8. Afraid of new situations				
9. Afraid of people				
10. Afraid of being alone				
11. Worries about illness and death				
MUSCULAR TENSION				
12. Gets stiff and rigid				
13. Twitches, jerks, etc.				
14. Shakes				
SPEECH PROBLEMS				
15. Stuttering				
16. Hard to understand				
WETTING				
17. Bed wetting				
18. Runs to bathroom constantly				
BOWEL PROBLEMS				
19. Soiling self				
20. Holds back bowel movements				
COMPLAINS OF FOLLOWING SYMPTOMS EVEN THOUGH DOCTOR CAN FIND NOTHING WRONG				
21. Headaches				
22. Stomach aches				
23. Vomiting				
24. Aches and pains				
25. Loose bowels				
PROBLEMS OF SUCKING, CHEWING or PICKING				
26. Sucks thumb				
27. Bites or picks nails				
28. Chews on clothes, blankets, or others				
29. Picks at things such as hair, clothing, etc.				
CHILDISH OR IMMATURE				
30. Does not act his age				
31. Cries easily				
32. Wants help doing things he should do alone				
33. Clings to parents or other adults				
34. Baby talk				
TROUBLE WITH FEELINGS				
35. Keeps anger to himself				
36. Lets himself get pushed around by other children				
37. Unhappy				
38. Carries a chip on his shoulder				

APPENDIX F

ANSWER ALL ITEMS

Observation	Not at All	Just a little	Pretty much	Very much
OVER ASSERTS HIMSELF				
39. Bullying				
40. Bragging and boasting				
41. Sassy to grown-ups				
PROBLEMS MAKING FRIENDS				
42. Shy				
43. Afraid they do not like him				
44. Feelings easily hurt				
45. Has no friends				
PROBLEMS WITH BROTHERS AND SISTERS				
46. Feels cheated				
47. Mean				
48. Fights constantly				
PROBLEMS KEEPING FRIENDS				
49. Disturbs other children				
50. Wants to run things				
51. Picks on other children				
RESTLESS				
52. Restless or over active				
53. Excitable, impulsive				
54. Fails to finish things he starts - short attention span				
TEMPER				
55. Temper outbursts, explosive and unpredictable behaviour				
56. Throws himself around				
57. Throws and breaks things				
58. Pouts and sulks				
SEX				
59. Plays with own sex organs				
60. Involved in sex play with others				
61. Modest about his body				
PROBLEMS IN SCHOOL				
62. Is not learning				
63. Does not like to go to school				
64. Is afraid to go to school				
65. Daydreams				
66. Truancy				
67. Will not obey school rules				
LYING				
68. Denies having done wrong				
69. Blames others for his mistakes				
70. Tells stories which did not happen				
STEALING				
71. From parents				
72. At school				
73. From stores and other places				
FIRE SETTING				
74. Sets fires				
TROUBLE WITH POLICE				
75. Gets into trouble with the police				
Why?				
PERFECTIONISM				
76. Everything must be just so				
77. Things must be done same way every time				
78. Sets goals too high				
ADDITIONAL PROBLEMS				
79. Inattentive easily distracted				
80. Constantly tugging				
81. Cannot be left alone				
82. Always climbing				
83. A very early eater				
84. Will run around between mouthfuls at meals				

APPENDIX F

85	Demands must be met immediately -- easily frustrated				
86	Cannot stand too much excitement				
87	Laces and zippers are always open				
88	Cries often and easily				
89	Unable to stop a repetitive activity				
90	Acts as if driven by a motor				
91	Mood changes quickly and drastically				
92	Poorly aware of surroundings or time of day				
93	Still cannot tie his shoelaces				

APPENDIX G

IV Listed below are descriptive terms of behavior. Place a check mark in the column which best describes this child

Observation	Degree of Activity			
	Not at all	Just a little	Pretty much	Very much
CLASSROOM BEHAVIOR				
1. Constantly fidgeting				
2. Hums and makes other odd noises				
3. Demands must be met immediately-easily frustrated				
4. Coordination, poor				
5. Restless or overactive				
6. Excitable, impulsive				
7. Inattentive, easily distracted				
8. Fails to finish things he starts-short attention span				
9. Overly sensitive				
10. Overly serious or sad				
11. Daydreams				
12. Sullen or sulky				
13. Cries often and easily				
14. Disturbs other children				
15. Quarrelsome				
16. Mood changes quickly and drastically				
17. Acts "smart"				
18. Destructive				
19. Steals				
20. Lies				
21. Temper outbursts, explosive and unpredictable behavior				
GROUP PARTICIPATION				
22. Isolates himself from other children				
23. Appears to be unaccepted by group				
24. Appears to be easily led				
25. No sense of fair play				
26. Appears to lack leadership				
27. Does not get along with opposite sex				
28. Does not get along with same sex				
29. Teases other children or interferes with their activities				
ATTITUDE TOWARD AUTHORITY				
30. Submissive				
31. Defiant				
32. Impudent				
33. Shy				
34. Fearful				
35. Excessive demands for teacher's attention				
36. Stubborn				
37. Overly anxious to please				
38. Uncooperative				
39. Attendance problem				

APPENDIX H

BEHAVIOUR CHECKLIST

Please complete the following items as they refer to Mark's behaviour today.

	NOT AT ALL	JUST A LITTLE	PRETTY MUCH	VERY MUCH
1. Picky and finicky eating.				
2. Nightmares.				
3. Awakens at night.				
4. Afraid of new situations.				
5. Wants help doing things he should do alone.				
6. Lets himself get pushed around by other children.				
7. Shy.				
8. Feelings easily hurt.				
9. Cries often and easily.				
10. Things must be done the same way every time.				

Do you think that Mark was given sugar at school today?

YES _____ NO _____ DON'T KNOW _____

APPENDIX I

TEACHERS BEHAVIOUR CHECKLIST

Please complete the following items as they refer to Craig's behaviour today.

	NOT AT ALL	JUST A LITTLE	PRETTY MUCH	VERY MUCH
1. Constantly fidgeting.				
2. Hums and makes other odd noises.				
3. Demands must be met immediately - easily frustrated.				
4. Restless or overactive.				
5. Excitable, impulsive.				
6. Inattentive, easily distracted.				
7. Fails to finish things he starts - short attention span.				
8. Quarrelsome.				
9. Defiant.				
10. Stubborn.				

APPENDIX J

OBSERVATIONAL CODES (adapted from Ballard, 1981)

<u>CODE</u>	<u>DEFINITION</u>
I	- an interaction. A reciprocal interchange between 2 individuals involving: a) a directed social stimulus (initiation) by one child, and b) an observable response to that stimulus by another child.
I →	- an interaction initiated by target child.
I ←	- an interaction in which target child responds to another child's initiation.
IV	- an interaction which involves speech.
IV+	- a positive verbal interaction. Talking or whispering to another child, or listening to another child.
IV-	- a negative verbal interaction. Talking with angry facial features or gestures and shouting.
IG	- a nonverbal interaction. The target child gives someone something or receives something from someone. Neither child says anything. This code defines sharing and is always a positive interaction, therefore, no positive or negative sign is needed.
IMG	- a non-verbal interaction which involves motor-gestural movements.
IMG+	- an affectionate physical contact (hug, hold hands) wave or other communicative gesture which is responded to by another.
IMG-	- a negative motor gestural interaction. Hitting, kicking, non-playful pushing, grabbing an object from someone's construction while they are present.
IA	- an interaction which is initiated by an adult or responded to by an adult.

APPENDIX J

- U - unoccupied behaviour. The child apparently is not playing, but is occupied with watching anything that happens to be of momentary interest. When there is nothing exciting taking place, s/he plays with her/his own body, gets on and off chairs, just stands around, follows the teacher, or sits in one spot glancing around the room. The child does not have play equipment.
- S - solitary independent play. The child plays alone and independently with toys that are different from those used by the children within speaking distance and makes no effort to get close to other children. S/he pursues her/his own activity without reference to what others are doing. The child has play equipment.
- O - onlooker. The child spends most of her/his time watching the other children play. S/he often talks to the children s/he is observing, asks questions, or gives suggestions, but does not overtly enter into the play her/himself. This type differs from the unoccupied in that the onlooker is definitely observing particular groups of children. The child stands or sits within speaking distance of the group, and does not have play equipment.
- P - parallel activity. The child plays independently but with toys that are like those the children around her/him are using. The child plays with the toy as s/he sees fit and does not try to influence or modify the activity of the children near her/him. S/he plays beside rather than with the other children.
- * A - associative play. The child plays with other children. There is borrowing and loaning of play material. All the members engage in similar if not identical activity, but there is no organisation of the activity around any material goal or product.
- C - co-operative or organized supplementary play. The child plays in a group that is organised for the purpose of making some material product, or of striving to attain some competitive goal, or of dramatising situations of adult and group life, or of playing formal games. The control of the group situation is in the hands of one or two of the members who direct the activity of the others.

* This code was not used in the present study.

APPENDIX K

Group	Treatment			
	1	2	3	4
1	A	B	B	A
2	A	B	B	A
3	A	B	A	B
4	B	A	B	A
5	B	A	A	B
6	A	B	A	B
7	B	A	B	A

Key

A = sugar

B = aspartame

APPENDIX L

Sample Breakfasts.

Fruits	Fruit juice, bananas, citrus fruit, tomatoes, raisins
Cereals/ Breads	Whole-grain cereals, toast, muffins
Eggs/meat protein	Boiled or scrambled eggs, yogurt, cheese, peanut butter U
Beverages	Milk

APPENDIX M

Means and standard deviations for behavior checklist scores

		Baseline	Sugar	Placebo
Parent	Boys (7) ¹	6.3 (2.3) ²	6.1 (2.9)	3.6 (3.3)
	Girls (8)	5.6 (3.7)	5.3 (3.8)	5.4 (7.2)
Teacher	Boys (9)	2.2 (2.5)	1.9 (1.3)	2.0 (1.6)
	Girls (9)	1.6 (1.8)	1.3 (1.2)	0.9 (0.6)

¹ = number of subjects

² = standard deviations

APPENDIX N

Means and standard deviations of observational behavior codes.

<u>Codes</u>		Baseline	Sugar	Placebo
Child initiated verbal interaction	Boys	31.7 (9.5) ¹	33.5 (9.9)	26.2 (8.7)
	Girls	27.3 (5.5)	26.8(10.1)	30.6(10.4)
Peer initiated verbal interaction	Boys	23.3 (6.3)	22.5 (8.3)	21.3 (5.2)
	Girls	25.2 (4.0)	24.0 (9.4)	24.0 (9.1)
Adult interaction	Boys	21.3 (9.1)	20.5 (9.1)	17.9(11.5)
	Girls	16.6(11.6)	16.4(11.1)	14.6(12.9)
Interactive play	Boys	18.7 (4.9)	19.8 (7.2)	16.8 (7.5)
	Girls	22.7(10.5)	25.4(13.4)	21.5 (9.5)
Non-interactive play	Boys	19.5(10.1)	15.6 (5.3)	25.4(11.4)
	Girls	17.1 (6.9)	18.8 (6.9)	13.6 (8.8)

¹ = standard deviations

number of subjects = 18

APPENDIX O

APPENDIX O

Key

B = Baseline

S = Sugar

A = Aspartame

S* = subject refused to drink sugar challenge drink

APPENDIX P

Nutrition Attitude Questionnaire Percentages

	Agreed to participate (n=22)					Refused to participate (n=16)				
	1	2	3	4	5	1	2	3	4	5
1. The food that we eat can affect the way we feel and behave.	50	40.9	9.1	0	0	75	18.8	6.2	0	0
2. Specific diets and vitamin supplements can provide alternatives to medication in the treatment of stress.	40.9	40.9	13.6	4.5	0	37.5	56.3	6.2	0	0
3. Health foods and natural foods without preservatives are better for your physical and mental health.	40.9	50	9.1	0	0	81.3	12.5	6.2	0	0
4. Hyperactivity in children is caused by food additives.	9.1	31.8	54.5	4.5	0	18.8	12.5	62.5	6.2	0
5. Junk foods eaten by children may affect their ability to learn in school.	13.2	45.5	27.3	9.1	0	31.3	37.5	18.7	12.5	0
6. The consumption of large amounts of candies, such as at Halloween, makes some children very excitable and hard to handle.	27.3	36.4	36.4	0	0	37.5	12.5	50	0	0

- 1 = strongly agree
- 2 = agree
- 3 = undecided
- 4 = disagree
- 5 = strongly disagree

END

1 1.0|4.86

FIN