EFFECTS OF SUCROSE ON PHYSICAL PERFORMANCE AND BRAIN CHEMICAL ACTIVITY

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On the occasion of the ISRF/CEFS Conference, Paris, March 1977 two papers were presented on the effects of sucrose on physical performance and brain chemical activity. These are summarized below. For those readers who wish to have additional information, Professor Brooke's text, and two previously published papers by Professor Wurtman are available upon request.

SUCROSE, WORK AND PERFORMANCE ERROR - A REVIEW OF CARBOHYDRATE NUTRITION FOR HUMAN PERFORMANCE

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"The concern of this review is with research statements which combine information about metabolism, possibly central nervous system modifications or responses, and subsequent human movement and its product, i.e. the performance. The present paper ... is concerned with the effects of varying the amount or types of carbohydrate in the diet upon human performance characteristics over a time span not exceeding at the most two to three weeks. Further, attention is to 'normal' human beings, that is those not clinically ill." And, because of "the marked individuality occurring in blood glucose response to (carbohydrate) nutrition, sensitive awareness of individual variation is called for."

Professor Brooke reported "considerable advances have been made in describing the very important role of carbohydrate nutrition in the support of sustained physical work. ... It has been demonstrated that the limits imposed by complete exhaustion of active muscle glycogen... (stored carbohydrate which serves as the primary source of energy for physical activity) can be extended by dietary sugars used to maintain performers during such physical work. Benade et al (1971), by introducing sucrose loads of 110 g or 200 g taken in the third hour of five hour shifts by Bantu workers sig-
nificantly increased the proportion of carbohydrate being utilized in the metabolic mixture and also significantly increased the efficiency of the workers (as measured by oxygen intake for a fixed amount of work). Brooke, Davis and Green (1975) by feeding carbohydrate during work on the laboratory cycle ergometer by racing cyclists also increased the efficiency of performance and elevated respiratory quotients. In a field situation Karlsson and Saltin (1971) demonstrated that when cross country ski racers were fed a high carbohydrate diet during a 30 km race, muscle glycogen levels were maintained higher and performance times were better than with no feeding. Also, Green and Bagley (1972) showed that for long distance canoeists provided with a dietary sugar drink both before and during racing activity, blood glucose levels during paddling were elevated on the high carbohydrate diet and mean lap times in the latter part of the activity were significantly maintained over those for a placebo drink. The demonstration by McKechnie, Reid and Joubert (1971) that restriction of sucrose intake prior to marathon running has a detrimental effect can be expected to have a similar foundation.

"It is clear that the provision of diets rich in carbohydrate can act to sustain physical work of high intensity extending over hours and to delay the onset of exhaustion."

"In addition to utilizing carbohydrate ingestion to maintain sustained demanding work, research has been pursued into the efficacy of such ingestion to aid recovery from exhaustion after such performance. Christensen and Hansen in 1939 reported that when subjects ingested 200 g of glucose at such times, they were able to continue the work task for up to a further hour. Brooke and Green (1974) developed upon this study by demonstrating that a glucose syrup drink of 1.486 MJ energy value resulted in significantly more work being completed in a second work task 40 minutes after exhaustion, in comparison to a control diet ...."

"... in recent years the most outstanding demonstration of the role of carbohydrate nutrition for (sustained physical) performance has been the group of studies demonstrating the capacity of local skeletal muscle glycogen stores for plastic adaptation. Bergström and Hultman (1967) demonstrated that during one leg exercise only the active muscles of the exercising leg become depleted of glycogen. There is no transfer from passive to active muscle. When subjects subsequently were fed high carbohydrate diets in comparison to fat or protein diets marked increase in these active muscle glycogen stores above initial resting levels was observed. The effect has subsequently been confirmed in a number of studies. ... It is clear that exercise bouts to exhaustion of local muscle glycogen stores when spaced three days apart and with ample carbohydrate available in the diet in the latter phase of the procedure in conjunction with the performance change result in very significant increases in local carbohydrate energy stores to as much as twice initial values. ...For reasons that are not at present clear the other available energy substrate, fat, does not appear to be
available to maintain performance at the intensities referred to above."

"In considering the role of carbohydrate nutrition in vigorous physical work it is appropriate to take cognizance of the need for dietary carbohydrates when accidental hypothermia or exposure is imminent due to accidents on outdoor expeditions. ... Planning to make carbohydrate nutrition available to meet such emergencies is essential.

"As well as attending to relationships with sustained physical work, researchers of carbohydrate nutrition in human performance have also attended to tasks where information processing and subsequent responses, ...are the main characteristics. ...A number of recent studies report results suggesting or indicating a relationship between level of blood glucose and fine skilled performance. ... Simpson, Cox and Rothschild (1974) through ingestion of 18 g of glucose in 100 ml of water by three hour fasting subjects demonstrated alleviation of performance impairment induced by 80 DBA white noise intruded into the environment of a pursuit rotor tracking task. The glucose fed group when not under sound stressor also showed a much shallower fall in blood glucose level back toward normal values during the test. However, in the no-noise condition glucose ingestion resulted in a fall in tracking performance. Brooke, Toogood, Green and Bagley (1973) reported a relationship between reduction in factory accidents and intake of glucose syrup drink to elevate worker's low respiratory quotients and blood glucose levels due to breakfast omission. Such studies suggest that ingestion of carbohydrate has an impact upon more delicate types of human performance."

"It is pertinent to question the basis for such effects. At the present time a number of hypotheses can be advanced. It is possible that the level of the blood glucose is either a determining or potentiating factor and two possible mechanisms already have support available. Firstly, it might be considered that lowered glucose levels below the typical fasting value act to challenge directly the metabolism of nerve cells. ... Indeed evaluation of brain arterio-venous gas differences indicates that approximately 93 per cent of cellular energy normally is derived from carbohydrate." Secondly, "recent work by Wurtman and Fernstrom (1974) has led to the proposal of an alternative hypothesis. ...that carbohydrate ingestion ... is acting to modify performance through modification of a central nervous system synaptic agent. Still attending to the integration of neural function a further hypothesis that cannot be discounted is that feelings of distress from fasting conditions are competing, at central nervous levels associated with perceptual selection, for central attentive space."

Professor Brooke concluded his presentation by stating: "With the gradual accumulation of empirical studies in closely related areas there is need now to study in the normal human being the relationship between carbohydrate ingestion, metabolic status, nervous system integration and skilled performance."
"The neurons of the brain utilize a group of chemicals, the neurotransmitters, to carry messages from one cell to another. The amount of information passing between cells thus depends on two factors, i.e., how frequently the neurons fire and release their neurotransmitter, and how many molecules are released each time the neuron fires.

"My associates and I have found that the quantity of one neurotransmitter, serotonin, that is released each time serotonin-containing neurons fire is influenced by each meal that the person or experimental animal eats. This is because the composition of the meal determines the levels in the bloodstream of various amino acids, including tryptophan, which is the precursor for brain serotonin. If the meal contains primarily sucrose or other simple carbohydrates, its main effect on plasma amino acid levels is mediated by the resulting secretion of insulin. This hormone lowers the plasma levels of neutral amino acids such as leucine, isoleucine, valine, tyrosine, and phenylalanine, that compete with tryptophan for uptake into the brain; thus brain tryptophan levels rise, and the synthesis of serotonin is accelerated; this, in turn, increases the amount of serotonin that is released each time the neuron fires. In contrast, if the meal contains a large amount of protein, then plasma levels of the competing neutral amino acids rise, far more than plasma tryptophan levels, since tryptophan is very scarce in proteins; hence brain tryptophan levels may fall, and, consequently, serotonin synthesis is slowed and serotonin release diminished.

"Serotonin-containing neurons are involved in a number of important brain functions. The release of serotonin decreases pain sensitivity, increases the likelihood of sleep, affects the secretion of hormones from the pituitary gland, and may also affect a number of higher brain functions, e.g., mood and memory. Serotonin-containing neurons are also involved in eating behavior, both in the hunger drive and in the choice of which particular foods to eat.

"The synthesis of another brain neurotransmitter, acetylcholine, is also under nutritional control. The consumption of foods rich in its dietary precursor, choline, increases the levels of acetylcholine in brain and other tissues, and also increases the physiological activity of cholinergic neurons. It seems probable that the composition of the diet will directly affect brain action in a variety of ways that could not have been anticipated a decade ago."

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