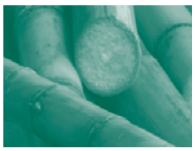

Carbohydrates and the cognitive performance of children

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As the brain needs a continuous supply of glucose, there has been recent interest in the relationship between the ability of the diet to influence the level of blood glucose and cognitive functioning. Because the brain of a child requires a greater percentage of the body's energy than an adult, there is increasing interest in the nature of the meals that children consume. There is consistent evidence that missing breakfast adversely influences cognition, particularly memory. These adverse effects can be reversed by the provision of starchy carbohydrates or sugars. When the composition of breakfast has been considered, meals that release glucose slowly into the blood have also been found to aid cognitive functioning in the late morning. The optimal amount or rate of glucose absorption in the blood for ideal cognitive functioning is therefore unknown. This article explores the effects of breakfast and its composition on children's cognition and school performance.

CARBOHYDRATES AND BRAIN FUNCTIONING

We need a varied and balanced diet and the Dietary Reference Intakes (DRIs) recommend that this should include between 45 to 65% of our daily energy from carbohydrate[1]. Those who are more active should have a higher percentage of calories in the form of carbohydrate. The consumption of carbohydrate results in the release of glucose into the blood where it is a major fuel for the body. In particular the brain needs a continuous supply of glucose.

The brain is unusual in that it typically uses glucose as its sole source of energy. When blood glucose levels are low, most tissues have other sources of energy such as ketones and fatty acids. In contrast, the brain normally uses only glucose; although after several days of fasting ketones can be metabolized. The importance of maintaining blood glucose levels reflects the brain's reserves of glucose that last only about ten minutes before they need to be replenished. The requirement for a continuous supply of glucose also reflects the intense metabolic activity of the brain.

Although the brain is only about 2% of the weight of the adult body, it accounts for about 20% of the basal metabolic rate. The adult brain uses glucose at the same rate that skeletal muscle does during vigorous exercise[2]. With children, the need for glucose is even greater as they have relatively larger brains than adults in relation to body size. A given amount of a child's brain tissue also uses more glucose than a comparable amount from an adult; the brain tissue of a four year old uses twice as much glucose as that of an adult[2]. This intense use of glucose continues until nine to ten years of age, after which the metabolic rate of the brain begins to decline, reaching adult rates in the late teenage years.

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The relatively larger size and metabolic activity of a child's brain has led to speculation that it might be particularly susceptible to the amount and rate at which blood glucose is released into the blood stream. It is, however, not necessarily the provision of dietary glucose that is the underlying mechanism; inevitably any change in the levels of blood glucose stimulates a range of hormonal responses that in turn may influence brain functioning.

Breakfast and cognition

After an overnight fast, glucose and glycogen stores from the previous day's meals are depleted, forcing the body to shift fuel sources and use fatty acids as the primary energy source. This results in the lowest concentration of blood glucose of the day. Children who do not eat breakfast

therefore go to school with blood glucose at fasting levels. The number of children who choose not to eat breakfast increases progressively with age and in the late teens can be as high as a third of those asked[3].

Given this background there has been interest in the influence that breakfast might have on cognition and behaviour during the morning. There is consistent evidence that those who miss breakfast suffer a negative impact on mood and memory in the late morning[4]. In addition, there is some evidence that a meal, if too small, may also be disadvantageous unless a mid-morning snack is provided. A study of nine year old children recorded what they had eaten for breakfast on two separate test days. On one of those test days, children were given a mid-morning snack consisting of a cereal bar[5]. In the late morning, those who had eaten a small breakfast (average 61 kcal), spent significantly less time attending to their school work than those who had eaten a larger breakfast. However, the adverse effect of a small breakfast was reversed by the consumption of a mid-morning snack. The provision of carbohydrate alone has been shown to reverse the adverse effects of fasting during the morning. The most common study approach that has been taken to increase the levels of blood glucose has been to provide a sugar-containing drink[6]. A tendency was found for improved mood and memory to result. For example, studies that measured memory by showing a series of objects and then asking for as many as possible to be recalled, reported improved recall following consumption of carbohydrate. On occasions, aspects of cognition such as the ability to sustain attention have also been found to improve.

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Sugar and behaviour and cognition

Although many parents believe that sugar makes their child hyperactive, systematic study has failed to support such a view; in fact, raising blood glucose has been reported to improve behaviour in school and memory in the morning[7]. A study in the United Kingdom gave children, aged nine to eleven years, either a glucose containing drink or a placebo in the afternoon. On the days children had the glucose drink (as an experimental procedure) they had better memories and spent more time on their school work[7]. There is a long series of well-designed, double-blind, placebo controlled studies that have produced no support for the suggestion that sugar encourages hyperactive behaviour[8].

It is also commonly believed that rapidly absorbed carbohydrates (such as sugar) cause large swings in blood sugar, in particular reactive hypoglycemia. The assumption is that sugars produce a rapid rise in blood glucose that is followed by a rapid fall to a level that disrupts the functioning of the brain. This is in fact a misconception as blood glucose concentrations remain relatively stable in healthy people; values rise following a meal and then fall, but typically do not fall to levels that would be considered hypoglycemic[9].

Eating sugar does not cause a rapid rise in blood glucose followed by a rapid fall to a level that disrupts the functioning of the brain. In fact, blood glucose concentrations remain relatively stable in healthy people; values rise following a meal and then fall, but typically do not fall to levels that would be considered hypoglycemic.

Composition of breakfast and school performance over the morning

There have been relatively few studies that have tried to establish the nutritional composition of the optimal breakfast to enhance a child's cognitive functioning[6]. However, the introduction of a school breakfast program tends to find a positive influence on academic performance, although the mechanism is unclear and in part may reflect better school attendance[10]. Furthermore, more recent research suggests that meals that combine macronutrients in a manner that reduces the glycemic load (GL)* may have a beneficial effect on the performance of children at school. This suggests that a balanced breakfast may be beneficial and that multiple dietary factors may be responsible for the benefits observed following breakfast consumption.

For example, in one study the same group of children, aged six to seven, ate three different breakfasts on different days[11]. Breakfasts were calorically equivalent but differed in their macronutrient composition

* Glycemic load is the glycemic index of a food multiplied by the amount of available carbohydrate of that food (Table 1).

and GL. Children were randomly assigned to one of three experimental meals (High, Medium and Low GL) each morning for four weeks. Two to three hours after eating, the GL of the breakfast influenced memory, the ability to sustain attention and the time spent on tasks when working individually in class. Those who consumed a lower GL breakfast tended to perform tasks better than those consuming a higher GL breakfast. It seems that while glucose has an important role in brain function, other metabolic effects of a balanced diet, such as provision of amino acids, are also of significance.

Evidence that a modest rate of glucose absorption into the blood is an important factor in cognitive behaviour was demonstrated in a second study of children aged six to eleven years, who on different days, received a low- or high-fibre breakfast (i.e., Coco Pops™ and All-Bran™ cereals, respectively), with the high-fibre breakfast also being higher in protein. The performance on a series of cognitive tasks declined over the morning, although the decline was less for measures of memory and attention when the high-fibre cereal had been eaten[12]. Similarly, a more recent study compared the influence of a high-fibre versus low-fibre breakfast on the cognitive functioning of adolescents where other aspects of the meal were equivalent[13]. The low-fibre meal consisted of corn-flakes and white bread, whereas the high-fibre meal offered muesli and an apple. Tests of attention and the speed of responding were faster after a high-fibre (low-glycemic index) meal. Table 1 defines glycemic index (GI) and GL and provides an example of how the numbers are derived.

Table 1: Definitions of glycemic index and glycemic load

Glycemic Index (GI)	Index that reflects the change in blood glucose after ingestion of a test food compared to the reference food, such as white bread or glucose.	GI of an apple = 34 (i.e. the carbohydrate in the apple provides 34% of the glycemic response of glucose)
Glycemic Load (GL)	Measure of the glycemic index of the food, taking into account the amount of available carbohydrate in a standard serving; this reflects the true effect on glycemia.	GL of an apple = 5 (i.e. amount of glycemic carbohydrate in the apple (14g) x GI/100 = 14 g x 34/100)

The sucrose content of a cereal is not a marker of a high-GI cereal. In fact, the glycemic response to sucrose is moderate and less than many other commonly consumed foods (Table 2). This is because sucrose consists of 50% glucose and 50% fructose, and so the glycemic response of sugar is reduced due to the fructose component. Therefore, the sucrose in ready-to-eat breakfast cereals of comparable total carbohydrate content does not increase the GI of those foods and may actually reduce the overall GL of the cereal. The GI of starchy foods depends on the nature of the starch and the way food is stored, cooked and processed. The GL of a meal can therefore be influenced by all of these factors as well as the macronutrient composition of the meal (i.e., by the amount of fat, protein, fibre, and available carbohydrate).

It is apparent that the GI (or GL) approach is not entirely precise; however the concept, meaning the rate at which glucose is released into the blood, may be important for cognition. If the GI of foods proves to influence children's school performance, then more attention will be directed to the types of foods that children are fed for breakfast. More research is needed to effectively answer this question. Sugar may prove helpful if it increases the palatability of low-GI foods without affecting the glycemic response.

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Table 2: Glycemic index values of various breakfast foods

HIGH 70+	Glucose	100
	Cornflakes	86
	Waffles	76
	Cream of wheat™, instant	74
	Bagel, white	72
	White bread	70
MEDIUM 55-69	English muffin	69
	Pancakes	67
	Table sugar (sucrose)	65
	Carrot muffin	62
	Mini Wheats™ cereal	58
	Honey	58
	Fruit cocktail, canned	55
LOW 20-54	All-bran™ cereal	51
	Starwberry jam	51
	Orange juice	46
	Chocolate milk, low-fat	34
	Yogurt, low-fat, sweetened	33
	Milk, skim	32
	Fructose	19

Source: International table of glycemic index and glycemic load values: 2002. Am J Clin Nutr 2002;76:5-56.

There is consistent evidence that missing breakfast is associated with a negative impact on mood and memory in the late morning, as well as spending less time on school work. In addition there is increasing evidence that the composition of breakfast (if eaten) also influences subsequent functioning. Raising blood glucose improves behaviour and cognition; however the optimal level and rate of glucose absorption is unknown. A working hypothesis is that meals that release glucose slowly over a prolonged period (either because they are high in protein and/or fibre or have a low-GL) are associated with better functioning in the late morning.

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