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Psychological effects of snacks and altered meal frequency

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Over the past two decades, substantial research has been conducted to investigate the idea that alterations in short-term nutritional intake play a role in influencing cognitive behaviour and mood. A portion of this research has examined specifically the effect of meal intake on the performance of mental tasks and subjective feelings of mood. Results of this research indicate that a number of variables including the timing and nutritional composition of the meal, nutritional status, habitual patterns of feeding behaviour, beliefs about food, and the nature of the mental tasks, can influence the effects of meals on cognitive behaviour. For example, studies have demonstrated that breakfast intake generally is associated with an improvement in cognitive performance later in the morning, while lunch intake is associated with an impairment in mid-afternoon performance on mental tasks and more negative reports of mood. Intake of nutrients late in the afternoon appears to have a positive effect on subsequent performance on tasks involving sustained attention or memory. Although research has provided insights into the role of meal intake on cognitive behaviour and mood, there are a number of factors which remain to be studied. These include the interaction of age, gender, activity level, meal composition, personality factors, stress with the effects of meals on cognitive behaviour. Additionally, more work is needed on the time-course of short-term nutrient effects, and the effects of chronic changes in meal intake on behaviour.

Eating behaviour: Snacks: Meal frequency: Cognitive behaviour: Mood

Nutrient intake plays a crucial role in the functioning of the nervous system and, therefore, behaviour. Deficiencies in intakes of a number of vitamins and minerals are accompanied by impairments in brain functioning and behavioural disturbances. Additionally, contamination of food supplies with heavy metals (e.g. Pb and Hg) adversely affects brain functioning and behaviour. In these circumstances, relatively-long-term exposure (e.g. weeks or months) to nutritional deficiencies or food contaminants are required before changes in neural functioning or behaviour are observed (Kanarek & Marks-Kaufman, 1991).

During the past 20 years, the idea that short-term alterations in nutritional intake also have a significant effect on neural functions such as learning, memory, information processing and mood, has gained acceptance. This acceptance stems, at least in part, from publications in the popular literature asserting that intake of certain types of foods or food components affect these neural processes. Until recently, however, these assertions have been predicated primarily on anecdotal reports rather than scientific investigations. Fortunately, over the past decade, research using appropriate experimental methods to examine the interaction between short-term nutritional intake and cognitive behaviour has flourished. A portion of this research has focused on the effects of meal frequency and composition on mental abilities. The present paper will review the results of this research to gain a better understanding of the ways in which meals can affect mental performance and mood.

BREAKFAST AND MENTAL PERFORMANCE

The belief that breakfast is the most important meal of the day has become part of conventional wisdom. Support for this belief has come from studies investigating the effects of breakfast intake on mental abilities and academic achievement in school-aged children (for example, Conners & Blouin, 1982–3; Pollitt *et al.* 1982–3, 1996; Pollitt, 1995; Table 1). Research endeavours in this area have concentrated predominantly on younger individuals for both theoretical and practical reasons. On the theoretical level, it has been assumed that since breakfast typically follows the longest period of fasting during the 24-h daily cycle, the omission of breakfast could significantly alter metabolism leading to decreased nutrient availability to the brain, and potentially detrimental behavioural outcomes (Pollitt, 1995). Because children have proportionately greater nutrient requirements to maintain normal development, and breakfast contributes substantially to both energy input and micronutrient intake of many children, it has been suggested that not having breakfast may have more deleterious effects in younger than in older individuals (Pollitt, 1995; Sampson *et al.* 1995). On a more practical level, studies have been directed towards evaluating the effectiveness of federally-funded feeding programmes, such as School Breakfast Programs in the USA and Peru, for improving academic performance (Meyers *et al.* 1989; Cromer *et al.* 1990; Pollitt, 1995; Sampson *et al.* 1995; Pollitt *et al.* 1996).

Experiments conducted between 1930 and 1980 offered preliminary evidence for the belief that not having breakfast could negatively influence school performance (Lininger, 1933; Keister, 1950; Tuttle *et al.* 1954; Conners, 1984). However, these experiments suffered from a number of weaknesses, including small sample size, poor experimental design, and the use of relatively few objective measures of cognitive behaviour. Fortunately, subsequent investigations have addressed many of these methodological problems. For example, to control for possible differences in nutritional history between subjects in experimental (breakfast) and control (no breakfast) feeding conditions, more recent studies have used cross-over designs in which each subject participates in both feeding conditions. Additionally, a number of experiments have achieved control over nutrient intake by requiring the subjects to sleep in the research facility on the nights immediately preceding the test days. Finally, these studies have employed more comprehensive, reliable test batteries to assess cognitive abilities.

Results of more recent studies have supported the conviction that breakfast intake can moderate performance on school-related tasks (Pollitt *et al.* 1981, 1982–3; Conners & Blouin, 1982–3; Simeon & Grantham-McGregor, 1989). For example, in two experiments using cross-over designs and multiple measures of cognitive functions, Pollitt *et al.* (1981, 1982–3) observed that not having breakfast impaired the problem-solving abilities of well-nourished 9–11-year-old American children. When tested in the late morning, the children made more errors on a matching task when they had not had breakfast than when they had eaten breakfast. Similarly, Conners & Blouin (1982–3) found that the same-aged children made significantly more errors on a computerized arithmetic test, and did more poorly on an attention task when they had not had breakfast than when they had consumed the meal.

Recent work from Israel suggests that the time between eating and the measurement of cognitive abilities may influence the outcome of studies investigating the effects of breakfast on behaviour (Vaisman *et al.* 1996). On the first day of the study, memory and learning were compared in 11–13-year-old children who had either not eaten breakfast or consumed breakfast at home approximately 2 h earlier. Only minor differences were observed between the performance of the two groups. Approximately two-thirds of the children (*n* 322) then were enrolled in a 14 d programme in which they received 30 g sugared cornflakes and 200 ml milk (30 g fat/l) each morning between 08.00 and 08.20 hours. The subjects were asked not to eat breakfast at home during this time. The remaining children were used as controls and received no instructions regarding breakfast intake. On the last day of the breakfast programme, all the children were again tested between 08.55 and 09.35 hours. Children who received the school breakfast did significantly better on the memory and learning tasks than either children who had not eaten breakfast (*n* 63) or children who had consumed breakfast at home (*n* 118). On the basis of these findings, the authors suggest that cognitive performance can be enhanced by a short interval (30 min) between breakfast and testing but not by a longer interval (2 h; Vaisman *et al.* 1996). Although these findings are intriguing, there are a number of issues which the authors do not address. For example, no information is given concerning the types of breakfasts consumed at home, or on the regular eating habits of the children. Additionally, it is possible that children who come to school without eating breakfast may suffer from poorer care taking, or other problems at home.

Nutritionally-at-risk children may be particularly vulnerable to the detrimental effects of missing breakfast (Simeon & Grantham-McGregor, 1989; Chandler *et al.* 1995; Pollitt *et al.* 1996). Using a cross-over design, Simeon & Grantham-McGregor (1989) found that stunted and previously-malnourished 9–10-year-old Jamaican children performed more poorly on tests of short-term memory and problem-solving ability when they had not eaten breakfast than when they had eaten a morning meal. Moreover, in a more recent study, also conducted in Jamaica, the same group of researchers determined that undernourished children's performance on a test of verbal fluency was significantly better when they had consumed a school breakfast than when they had not (Chandler *et al.* 1995). Similarly, in an experiment in Peru, Pollitt *et al.* (1996) found that omitting breakfast adversely affected performance on a short-term memory task in children classified as nutritionally-at-risk. It should be noted, however, that cognitive performance did not vary as a function of breakfast intake for well-nourished children in either Jamaica or Peru. These results can be contrasted with those of studies in the United States in which missing breakfast had detrimental effects on the cognitive performance of well-nourished children (Pollitt *et al.* 1982–3; Conners & Blouin, 1982–3). One explanation for this discrepancy is that in developing countries even adequately-nourished children may be more accustomed to missing breakfast and, thus, less susceptible to the negative outcomes of not eating a morning meal than children in the USA (Pollitt, 1996).

In contrast to the observation that not eating breakfast negatively affected nutritionally-at-risk children in Peru and Jamaica, in a study conducted in Chile, no consistent associations were found between breakfast intake and performance on three computer-based cognitive tasks measuring visual memory, problem-solving ability and attention in either children who were classified as nutritionally-at-risk or normal children (Lopez *et al.* 1993). Several factors may have contributed to these contradictory findings. In the experiments conducted in Peru and Jamaica, short-term nutritional intake was controlled by admitting children to a research centre on the evening before the experiments (Simeon & Grantham-McGregor, 1989; Pollitt *et al.* 1996). In contrast, in the Chilean study, children remained at home the night before experiment making in more difficult to control previous nutritional intake (Lopez *et al.* 1993). Moreover, differences in testing conditions (children were tested in a laboratory setting in the studies in Jamaica and Peru, and at school in the Chilean study) make it hard to make direct comparisons among these studies. However, the most important difference between the studies may be task demand or motivation to perform the tests. Lopez *et al.* (1993) reported that the computerized tasks used in the study in Chile were very appealing to the children, and hypothesized that the

Table 1. *Summary of studies examining the effects of acute breakfast intake on cognitive behaviour*

Reference	Subjects	Country	Nutritional manipulation	Results
Children				
Pollitt *et al.* (1982–3)	9–11 years	USA	Breakfast *v.* no breakfast compared, within-subjects cross-over design	Poorer performance on matching figure task when children missed breakfast
Conners & Blouin (1982–3)	9–11 years	USA	Breakfast *v.* no breakfast compared within-subjects crossover design	More errors on an attention task when children missed breakfast
Simeon & Grantham-McGregor (1989)	9–10·5 years Previously malnourished and well-nourished children	Jamaica	Breakfast or no breakfast compared, within-subjects cross-over design	Lower scores on memory and fluency task when previously-malnourished children missed breakfast. No differences in well-nourished children
Lopez *et al.* (1993)	9–11 years Previously malnourished and well-nourished children	Chile	Breakfast or no breakfast compared, within-subjects cross-over design	No difference in performance as a function of breakfast intake in either nutritional condition
Pollitt *et al.* (1996)	9–11 years Nutritionally at risk and no risk	Peru	Breakfast or no breakfast compared, within-subjects cross-over design	Lower scores on memory task when nutritionally-at-risk children missed breakfast. No differences in no-risk group
Vaisman *et al.* (1996)	11–13 years	Israel	School breakfast compared with breakfast at home or no breakfast, between-subjects design	Poorer scores on memory test in children who ate no breakfast or had breakfast at home 2 h before test than in children who had breakfast in school 30 min before test
D. P. Wyon & I. Wyon (unpublished results)	10 years	Sweden	Large breakfast (e.g. cereal, yoghurt, sandwiches and milk) or small breakfast (e.g. sweet rolls and sweet drink), within-subjects cross-over design	More mistakes on attention task, decreased physical endurance with small breakfast than with large breakfast
Adolescents				
Dickie & Bender (1982)	13–17 years	Great Britain	Breakfast or no breakfast compared, within-subjects cross-over design	No differences in tests of short-term memory, attention or vigilance as a function of breakfast

(*continued*)

Table 1. *continued.*

Reference	Subjects	Country	Nutritional manipulation	Results
Cromer *et al.* (1990)	13–17 years	USA	School breakfast (doughnut, chocolate milk and orange juice) or low-energy breakfast (diet gelatine and no-energy drink)	No differences in tests of short-term memory, vigilance, mood or impulsiveness as a function of breakfast
Adults				
Spring *et al.* (1986)	18–65 years men and women	USA	High-protein (turkey) or high-carbohydrate (sorbet) breakfast, between-subjects design	High-carbohydrate meal associated with increased sleepiness in women and increased calmness in men
Benton & Sargent (1992)	University students	Great Britain	Breakfast *v.* no breakfast, between-subjects design	Poorer performance on memory task in students who did not eat breakfast than in those who ate breakfast
Smith *et al.* (1992)	University students	Great Britain	Breakfast *v.* no breakfast	Impaired performance on memory tasks in subjects who missed breakfast

children's motivation to perform these tasks may have overcome the negative effects of missing breakfast (Lopez *et al.* 1993).

While most studies have simply compared performance on cognitive tasks when children have or have not consumed breakfast, research conducted in Sweden by D. P. Wyon and I. Wyon (unpublished results) suggests that the nutritional composition of a breakfast meal also can influence accomplishments on school-related tasks. Performance of healthy 10-year-old children on tests of cognitive functioning was compared following consumption of either a breakfast consisting of a bowl of yoghurt with cereal, one or two open cheese or meat sandwiches, orange juice, and milk, or a breakfast consisting of a sweet drink, bread and jam or sweet rolls. The children worked faster, made significantly fewer mistakes on tasks requiring sustained attention, demonstrated greater physical endurance, and appeared less tired to teachers on days when they had eaten the breakfast containing yoghurt, cereal and sandwiches than on days when they had consumed a sweet drink and rolls. As this latter meal parallels the breakfast intake of many children, these results could have implications for school breakfast programmes and nutrition education plans. However, because the two breakfasts differed along a number of dimensions, including the percentage of daily energy intake, and the percentage of daily protein and fat intake, it is not possible to determine what component(s) in the meals played a role in improving cognitive performance.

Adolescents also may be vulnerable to the negative consequences of not eating breakfast. This age-group is undergoing rapid growth and experiencing a number of changes in metabolism associated with puberty. Furthermore, as a result of pressure from their peers and the media to maintain a slender body, adolescents may be more likely to miss breakfast than younger individuals. It has been reported that more than 35 % of adolescents in the USA (Cromer *et a.* 1990) and the UK (Bull, 1992), and 21 % of adolescents in Finland (Helakorpi *et al.* 1996) regularly miss breakfast. Finally, because the conceptual complexity of academic work increases substantially during adolescence, this may be a time when short-term fasting may be particularly detrimental. Unfortunately, there are only two published studies addressing the issue of breakfast intake on cognitive performance in adolescents (Dickie & Bender, 1982; Cromer *et al.* 1990). In the first study conducted in the UK, tests of short-term memory, vigilance and attention failed to discriminate between adolescents who had or had not consumed breakfast (Dickie & Bender, 1982). Similarly, in a more recent study in the USA, no differences in performance on tests of short-term memory, vigilance, impulsivity and mood were found between healthy adolescents who had consumed either a school breakfast consisting of a doughnut, chocolate milk and orange juice, or a low-energy breakfast consisting of diet gelatine and a no-energy drink (Cromer *et al.* 1990).

Although the results of studies with adolescents suggest that overnight fasting does not adversely affect cognitive functioning in this age-group, care should be exercised in interpreting these results. In contrast to experimental investigations of breakfast intake in younger children which employed cross-over paradigms, (Pollitt *et al.* 1982–3, 1996; Conners & Blouin, 1982–3; Simeon & Grantham-McGregor, 1989), between-group designs were used in the studies with adolescents. Thus, the subjects' previous nutritional history was not well controlled. Second, the adolescents in both studies were well-nourished and, thus, may have been less susceptible to the deleterious effects of missing breakfast than a less-affluent population (Dickie & Bender, 1982; Simeon & Grantham-McGregor, 1989; Cromer *et al.* 1990; Pollitt, 1995). Finally, it is interesting to note that the school breakfast provided in the study by Cromer *et al.* (1990) was similar to the breakfast of sweet rolls used in the study conducted by D. P. Wyon and I. Wyon (unpublished results) in Sweden. Thus, it may be that the nutrient composition of the breakfast was insufficient to lead to improvements in cognitive performance.

Experimental investigations provide only a momentary picture of the effects of breakfast intake on cognitive performance. This is because in these studies, performance is tested only once in each nutritional condition. Thus, these studies cannot answer the question does not eating breakfast on a regular basis have deleterious behavioural consequences. This may be, however, the critical question with respect to scholastic performance. Recent work conducted in a low-income setting in the USA revealed that on any given day 12–26% of children attended school without having eaten breakfast (Sampson *et al.* 1995). Additionally, these children were more likely to suffer from marginal nutritional deficiencies than children who regularly consumed a morning meal (Sampson *et al.* 1995). Field studies assessing the effect of government-funded school breakfast programmes furnish evidence for the educational benefits of consuming a morning meal (Powell *et al.* 1983; Meyers *et al.* 1989; Pollitt *et al.* 1996). For example, in a study conducted in Lawrence, MA, children in the third to sixth grades who participated in the School Breakfast Program across the school year showed greater improvements on standardized achievement tests, and had lower rates of absence and tardiness than children who qualified for the programme but did not participate (Meyers *et al.* 1989). Similarly, in a study in Peru, children who participated in a school breakfast programme for 3 months had lower absence rates, and higher scores on a vocabulary test than children who did not participate in the programme (Pollitt *et al.* 1996).

The number of adults who regularly miss breakfast in the USA and other Western countries has increased over the past 25 years (Haines *et al* 1996; Helakorpi *et al.* 1996). Although limited in number, recent studies suggest that breakfast intake can influence cognitive behaviour in adults as well as in younger individuals. For example, Benton &

Sargent (1992) reported that university students who did not eat breakfast did more poorly on memory tests than students who consumed a morning meal. In comparison, Smith *et al.* (1992, 1994), using a similar population, found that not eating breakfast impaired performance on free recall and recognition memory tasks, but did not alter performance on semantic memory or sustained attention tasks, and actually improved effectiveness on a logical-reasoning task.

In conclusion, experimental evidence suggests that omitting breakfast negatively affects cognitive functioning. However, it is important to note that there are a number of variables which can interact with the effects of breakfast intake on subsequent mental tasks. For example, marginal nutritional deficiencies may make individuals more susceptible to the adverse consequences of not eating breakfast (Pollitt, 1995). Age, body composition, gender, activity levels, patterns of food intake, socio-economic status and cultural variables also may modify the relationship between breakfast intake and mental functioning. Additionally, the timing of nutrient-related changes in behaviour needs to be considered. Most experiments have examined cognitive behaviour at only one time-point after breakfast. Thus, at present, no information is available on the time-course of the effects of breakfast on behavioural measures. Finally, the impact of not eating breakfast on mental performance clearly varies with the nature of the cognitive task.

THE EFFECTS OF LUNCH ON COGNITIVE BEHAVIOUR AND MOOD

Both observations of individuals in a work environment and experimental studies have established that the consumption of a mid-day meal can impair mental functioning (Hutchinson, 1952; Blake, 1967; Hildebrant *et al.* 1974; Christie & McBrearty, 1979; Craig *et al.* 1981; Craig, 1986; Smith & Miles, 1986*a*, *b*; Smith *et al.* 1988, 1990, 1991; Craig & Richardson, 1989; Lloyd *et al.* 1994). In naturalistic settings, reductions in alertness and efficiency are observed shortly after lunch relative to the morning or late afternoon hours. For example, errors made by shift workers, falling asleep while driving and lapses of attention by locomotive engineers reach a maximum after lunch at approximately 14.00 hours (Craig, 1986). Additionally, laboratory investigations have revealed that consumption of a mid-day meal is followed by feelings of lethargy and decrements in performance on mental tasks (Hutchinson, 1952; Craig *et al.* 1981; Craig, 1986; Smith & Miles, 1986*a*, *b*; 1987; Smith *et al.* 1988, 1990, 1991; Craig & Richardson, 1989). The decline in mental functioning which occurs following the consumption of a mid-day meal is referred to as the post-lunch dip.

It has been hypothesized that the post-lunch dip may simply reflect an endogenous alertness rhythm (e.g. Hildebrant *et al.* 1974). In support of this hypothesis, mid-afternoon decrements in performance are observed on some tasks whether or not lunch is eaten. However, for other tasks, performance at mid-day is impaired to a greater degree in subjects who have consumed lunch than in those who have not, indicating that food intake can contribute to the post-lunch dip (Craig *et al.* 1981; Craig, 1986; Smith & Miles, 1986*a*,*b*; Smith & Miles, 1987; Smith *et al.* 1988, 1990, 1991; Craig & Richardson, 1989). For example, Smith & Miles (1987) found that ingestion of lunch had no effect on performance on a reaction-time task. Both subjects who ate lunch, and subjects who skipped lunch did more poorly on the task in the afternoon than in the morning. In contrast, lunch intake did affect performance on vigilance and memory tasks. Subjects who ate lunch detected fewer targets on a vigilance task, and were slower on a memory task than those who did not eat lunch (Smith & Miles, 1986*b*, 1987).

Lunch intake can affect not only performance on mental tasks, but also mood. After lunch, subjects typically report decreases in feelings of alertness and anxiety, and an increase in feelings of fatigue. In contrast, subjects who abstain from eating lunch describe feeling more alert and anxious in the early afternoon than they had in the late morning (Smith *et al.* 1988).

The degree to which lunch moderates subsequent cognitive performance and mood may be mediated by a number of factors. One of the most obvious of these factors is meal size. In a study investigating the effect of meal size on attention and mood, Smith *et al.* (1991) reported that subjects who ate a larger than usual lunch made more errors on attention and search tasks than those who ate a normal-sized lunch, or one which was smaller than usual. No differences in mood were noted as a function of meal size, with subjects in all meal conditions declaring that they felt more feeble, dreamy and bored, and less alert, energetic, quick-witted and friendly after lunch than before the meal. Similarly, Craig & Richardson (1989) found that relative to their performance before lunch, young men made significantly more errors on a letter-cancellation task after eating a large lunch, but tended to make less errors after a small lunch. However, the relationship between the meal and the subjects' habitual eating behaviour appeared to be the most important factor affecting afternoon performance. More specifically, changes in performance were greater when subjects ate a lunch different in size to that which they normally consumed than when they ate a meal similar in size to their normal lunch. Thus, men who typically ate very little at lunch showed a greater decrement in performance after the large lunch than men who normally ate a heavy lunch. Conversely, performance improved to a greater degree after the small lunch in subjects who typically ate a heavy lunch than in those who ate a light lunch. These results indicate that both experimental lunch size and habitual lunch size contribute to the post-lunch dip.

Another factor to consider in studies examining the effects of lunch on cognitive behaviour is the timing of the meal and test measurements. The post-lunch dip in performance begins approximately 1 h after lunch, and continues for at least 1 h after that (Craig, 1986). Although some data suggest that performance recovers in the late afternoon (Craig, 1986), there are no well-controlled studies assessing the duration of the post-lunch dip. Several studies, however, have investigated whether the post-lunch dip is altered by the time at which lunch is eaten (Hammer, 1951; Craig, 1986; Smith & Miles, 1986*a*). Lunch time does not affect the post-lunch dip, when the meal is consumed within the range of what is considered normal (i.e. 11.00–14.00 hours).

Personality factors also may interact with the effects of lunch on later tests of mental abilities. For example, the less-neurotic and more-extroverted an individual scored on the Eysenck Personality Inventory, the greater the post-lunch dip in accuracy on either a letter-cancellation tasks or a perceptual-discrimination task (Christie & McBrearty, 1979; Craig *et al.* 1981). Additionally, Smith & Miles (1986*a*) observed the post-lunch dip was more pronounced in subjects who scored low on tests of anxiety than in subjects who scored high on these tests. Last, high levels of arousal may lessen the detrimental effect of lunch on the performance of cognitive tasks. For example, high levels of background noise (Smith & Miles, 1986*a*), and caffeine intake (Smith *et al.* 1990) can offset certain aspects of the post-lunch dip in performance efficiency.

Finally, it should be noted that not all aspects of cognitive performance are negatively affected by the consumption of lunch. Tasks which require sustained attention, such as cognitive-vigilance tasks, letter-cancellation tasks, perceptual discriminations and search tasks appear to be most sensitive to the detrimental consequence of lunch. In contrast, tests that require higher cognitive processes, such as mathematical reasoning, logical thinking and reading skills, may be less influenced by meal intake (Kanarek & Swinney, 1990).

Although there is now substantial evidence of a post-lunch dip in mental ability, more research is needed. For example, since the majority of experiments in this area used healthy young men as experimental subjects, the effects of gender, age, and nutritional status on cognitive performance following lunch are not known. Also, as mentioned previously, there have been no systematic investigations of the duration of post-lunch decrements in behaviour. Moreover, to better understand the effects of dietary manipulations on functional abilities, there is a need to expand the range of cognitive tasks used in this research and to determine the mechanism(s) for the detrimental consequences of lunch on cognitive behaviour. Finally, it should be noted that although lunch intake may impair performance on mental tasks on an acute basis, there is no information concerning the chronic effects of an afternoon meal on cognitive behaviour. Thus, on the basis of the available data one cannot conclude that eating lunch on a regular basis would have adverse effects on behaviour. Indeed, because lunch can provide a substantial proportion of daily nutrients, over the long term, it could be hypothesized that not eating lunch may be more detrimental than eating lunch to both general health status and mental functioning.

THE ROLE OF THE MACRONUTRIENT COMPOSITION OF A MEAL ON COGNITIVE BEHAVIOUR AND MOOD

The majority of studies investigating the effects of meals on subsequent mental abilities and mood have simply compared performance in subjects who have or have not consumed a meal. However, the macronutrient composition of the meal may be important with respect to both performance efficiency and mood (Lieberman *et al.* 1986; Spring, 1986; Spring *et al.* 1986; Smith *et al.* 1988, 1994; Kelly *et al.* 1994; Lloyd *et al.* 1994). In initial work exploring the effects of nutrient composition on cognitive performance, Spring *et al.* (1986) examined cognitive performance and mood in healthy adults between the ages of 18 and 65 years who had consumed either a high-carbohydrate meal (non-dairy sherbet) or a high-protein meal (turkey breast) for breakfast or lunch. With respect to mood, women who ate the carbohydrate meal described themselves as sleepier than women who ate the protein meal, while men who ate the carbohydrate meal characterized themselves as feeling calmer than men who ate the protein meal. These mood changes were reported whether the meals were eaten at breakfast or lunch time. Additionally, when the meals were given at lunch, subjects who ate the carbohydrate meal performed more poorly on dichotic listening, a test of sustained selective attention, than those who ate the protein meal. The effect of meal composition on performance, however, was only significant for individuals over 40 years of age. These results suggest that the macronutrient composition of a meal may affect mental abilities and mood. However, they must be viewed with caution because the study suffers from a number of methodological weaknesses. First, there were no pre-meal determinations of performance or mood. Second, a between-subject design was used and, thus, nutritional history was not well-controlled. Third, the meals were of fixed size, which means that relative to their normal lunch, some subjects, particularly the males, may have been eating less than usual. Additionally, because subjects knew what they were eating and the foods were not standard breakfast or lunch items, preconceived ideas about the effects of the foods on behaviour could have biased the results (Kanarek & Orthen-Gambill, 1986).

A second study by the same group of investigators (Lieberman *et al.* 1986) attempted to eliminate some of the preceding weaknesses by using a within-group design, and by determining mood before and after lunch. In this study, young men ate both a carbohydrate-rich (pitta bread) and protein-rich (turkey breast salad) lunch on two different days separated by 1 week. Half the subjects received the carbohydrate-rich meal on day 1, while the remaining subjects received the protein-rich meal. Mood was assessed preceding and at several times after lunch, while performance on multiple cognitive tasks was determined after the meal. Sleepiness increased and subjective vigour declined over the course of the afternoon. However, neither sleepiness nor vigour differed as a function of meal composition. Additionally, relatively few of the cognitive tests revealed any nutrient specific effects. The only significant findings were that reaction times to an auditory stimulus were slower, and performance on a digit-symbol-substitution test were poorer after subjects had eaten the carbohydrate meal than after they had consumed the protein meal. Again, however, these findings are difficult to interpret because no baseline measures are available to determine whether the carbohydrate meal actually impaired efficiency compared with the pre-meal period.

To further investigate potential differences in cognitive abilities and mood resulting from meals high in carbohydrate or protein, Smith *et al.* (1988) compared mood and cognitive performance in the same six male and six female subjects after they had eaten isoenergetic protein and carbohydrate meals. Two carbohydrate meals were provided, one high in starch and the other high in sugar. Each meal was designed to be equivalent to one-third of the subject's total daily energy requirement. Subjects rated their mood, and completed a 'focused attention' and a 'search' test preceding and 1 h following lunch. Subjects reported feeling more lethargic, clumsy, dreamy, bored and mentally slow after the meal. However, the composition of the meal did not influence these mood ratings. With respect to performance, reactions to peripheral targets were slower after the high-carbohydrate meals than after the high-protein meal, whereas, susceptibility to distracting stimuli was greater after the high-protein lunch than after the high-carbohydrate meals.

The fat content of the mid-day meal, also, may influence subsequent cognitive efficiency and mood (Lloyd *et al.* 1994; Smith *et al.* 1994). In support of this possibility, Lloyd *et al.* (1994) found that reaction times to a simple stimulus were longer, and subjects rated themselves as more drowsy, uncertain and muddled, and less cheerful when they had consumed either a low-fat–high-carbohydrate or high-fat–low-carbohydrate lunch than when they had consumed a medium-fat–medium-carbohydrate meal. As the medium-fat–medium-carbohydrate meal was most similar in size and macronutrient content to the subjects' habitual lunch, it may be that the results reflect responses to changes in normal intake rather than to the specific macronutrient composition of the meals. Additionally, it should be noted that while the high-fat and low-fat lunches impaired performance on a reaction-time test, they did not alter performance on either a memory test or a test of sustained attention. Smith *et al.* (1994) found that subjects who consumed high-fat meals for lunch responded more slowly, but more accurately on selective attention tasks than subjects who consumed low-fat meals. The fat content of the meals, however, did not alter performance on logical reasoning or cognitive vigilance tasks, and had only minimal effects on mood state.

In concert with the results of the preceding experiments, few effects of the energy and/or macronutrient composition of a lunch-time meal on cognitive performance were found in two recent experiments (Kelly *et al.* 1994). In both experiments, which were conducted in a residential laboratory to ensure precise measurements of food intake, healthy young men completed psychomotor tasks before and after consuming lunches varying in both energy, and carbohydrate and fat content. Both the energy and macronutrient content of the meals were covertly altered to control for the possible effects of expectations about the meals on behaviour. In general, performance on the tasks was poorer after lunch than preceding the meal. However, no systematic variations in performance were noted as a consequence of either the energy or macronutrient content of the lunch meals.

Taken together, the results of research investigating the interaction between the macronutrient composition of a meal and behaviour indicate that generalizations cannot be made about the positive or negative effects of intake of a particular macronutrient on behaviour. Although differences in cognitive performance and mood have been observed as a function of the macronutrient content of a meal, these differences generally have been small, inconsistent, and restricted to performance on a limited number of cognitive tasks (Lieberman *et al.* 1986; Spring *et al.* 1986; Smith *et al.* 1988, 1994; Lloyd *et al.* 1994).

SNACKS AND COGNITIVE BEHAVIOUR

Between-meal eating, or 'snacks', can contribute a substantial proportion of energy to total daily energy intake. Snacking behaviour is particularly prevalent in children, adolescents and young adults (Bull, 1992; Cross *et al.* 1994; Summerbell *et al.* 1995; Ruxton *et al.* 1996; Gatenby, 1997). Although snack intake occurs throughout the day, snacking occurs most frequently in the late afternoon (Cross *et al.* 1994). It is generally assumed that because snack foods often contain significant amounts of fats and/or sugars, that they are detrimental to health. However, it should be recognized that snacks can contribute to the nutritional quality of the diet (Cross *et al.* 1994; Gatenby, 1997).

Afternoon snacks also may have positive effects on cognitive performance (Kanarek & Swinney, 1990). To investigate this possibility, the performance of male and female college students on tests of attention, memory, arithmetic reasoning, and reading speed and comprehension was compared after they had consumed either a energy-rich snack (a confectionery product or fruit-flavoured yoghurt) or a no-energy snack (lemon–lime-flavoured diet soda). Each subject came to the laboratory for breakfast on the same day of the week for four consecutive weeks, and were tested under four different nutritional conditions. On two test days, subjects ate a standard lunch and on two days they did not eat lunch. The lunch–no-lunch conditions were factorially crossed with a energy-rich snack–no-energy snack conditions. Testing was begun 15 min and continued for 1 h after the snack was consumed. Both male and female subjects responded significantly faster on the attention task and remembered more digits in the memory task when they had consumed a high-energy snack than when they had drunk the no-energy soft drink. No differences in performance were observed as a function of lunch. However, this result is limited because pre-lunch performance was not determined in this study.

Although the results of this experiment suggest that an afternoon snack can improve cognitive performance, particularly on tasks requiring sustained attention, these results can be considered only preliminary in nature. Additional work is required to determine how the energy and/or macronutrient content of the snack, the age and nutritional history of the subjects, and the nature of the cognitive tasks interact with the effects of snack intake on cognitive behaviour.

THE EFFECTS OF EVENING MEALS ON COGNITIVE PERFORMANCE AND MOOD

To date, only one experiment has addressed the effects of an evening meal on cognitive performance and mood (Smith *et al.* 1994). In this experiment, mood and performance on cognitive tasks, similar to those used in research examining the effects of breakfast and lunch on behaviour (e.g. Smith & Miles, 1987; Smith *et al.* 1990, 1991, 1992), were compared in college students who either ate a standard evening meal, or missed the meal. After 1–3 h, subjects who consumed the meal reported feeling stronger, more proficient and more interested than subjects who did not consume the meal. Additionally, 90 min after the meal, subjects who had eaten completed more sentences on a logical-reasoning task than those had not eaten. No other differences in cognitive performance, however, were observed between subjects in the two meal conditions.

The results of this study suggest that an evening meal plays a limited role in determining subsequent performance on mental tasks. However, the limited amount of research makes it premature to draw any definitive conclusions about the effects of a dinner meal on cognitive behaviour.

CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH

Clearly, the research cited in this paper represents only a beginning of our understanding of the effects of short-term nutrient intake on behaviour. Although meal intake may have an impact on psychological functioning, the specific ways in which consumption of meals alters performance of mental tasks and mood are obviously dependent on a number of factors. Time of day may be the most significant of these factors. Missing breakfast can have detrimental consequences on behaviour, while omitting lunch actually can prevent post-lunch decrements in cognitive performance. A late afternoon snack may counteract these decrements.

Future research is needed to address a number of questions, including the interaction between age, gender, personality factors, activity level and nutritional history and the effects of meals on cognitive behaviour and mood. Another issue which has not been considered in previous studies is subjects' expectations about food. Individuals may have particular beliefs about how a food influences their behaviour, and bring these expectations into the experimental situation. For example, subjects' belief that high-carbohydrate foods provide a quick burst of energy could influence their response on cognitive tasks.

Finally, the mechanism(s) controlling meal-related effects on cognitive behaviour and mood remain to be elucidated. Alterations in a number of physiological variables, such as blood glucose and insulin levels (Pollitt *et al.* 1981, 1982–3; Benton & Sargent, 1992; Benton & Owens, 1993), or brain serotonin levels (Spring, 1986; Spring *et al.* 1986) have been suggested as potential mediating factors. However, at present, there is no firm evidence in support of either of these mechanisms.

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DISCUSSION OF THE PAPER

Comment by D. Benton

A series of studies have reported that missing breakfast is associated with poorer memory. There is also evidence that increasing the level of blood glucose is associated with better memory and the ability to sustain attention. The possibility that poor memory after missing breakfast may reflect the supply of blood glucose is considered. The evidence that the provision of blood glucose may increase the synthesis of acetylcholine, a neurotransmitter involved in the modulation of memory is discussed.

An improvement in memory, in those who had eaten breakfast, has been found to correlate with the levels of blood glucose (Benton & Sargent, 1992). In subsequent studies not eating breakfast was found to affect memory adversely for a word list, memory for a story and the ability to recall items while counting backwards (Benton & Parker, 1997). The effect seems to be particularly associated with memory, as a failure to eat breakfast did not influence other tasks. There are several other reports that memory is better following the eating of breakfast (Pollitt *et al.* 1982–3; Michaud *et al.* 1991; Smith *et al.* 1992, 1994).

A role of blood glucose in the impact of breakfast on memory was suggested by the finding that with two memory measures, a glucose-containing drink raised the performance of those who had not eaten breakfast to the level of those who had (Benton & Parker, 1997). However, as the provision of a source of blood glucose nullified the negative effects of not eating breakfast in some but not all situations, it seems that more than one mechanism is involved.

That an increased source of blood glucose benefits other aspects of cognition is gaining support. In both adults (Moser *et al.* 1983; Benton 1990; Benton *et al.* 1994) and children (Benton *et al.* 1987) a glucose drink has been found to improve the ability to sustain concentration. Keul *et al.* (1982) found that the number of errors made in the drinking-simulator decreased when a glucose drink was taken. The impression that memory, rather than other aspects of cognition, is more susceptible to changes in blood glucose levels, is unavoidable. A glucose-containing drink has been found to improve memory in both young healthy adults (Lapp, 1981; Benton & Owens, 1993; Benton *et al.* 1994; Parker & Benton, 1995) and the elderly (Hall *et al.* 1989; Manning *et al.* 1990; Craft *et al.* 1992, 1993).

When the question arises as to the mechanism by which an enhanced provision of glucose might facilitate memory the possibility that cholinergic activity is enhanced has attracted particular attention; an association between acetylcholine-mediated neurotransmission and memory is well documented (Kopelman, 1986).

Acetylcholine is formed, by choline acetyltransferase (*EC* 2.3.1.6), from the precursors choline and acetyl-CoA; glucose is the main source of the acetyl groups used in the formation of acetyl-CoA (Tucek, 1983). Choline acetyltransferase is not a saturated enzyme, therefore an increased supply of acetyl-CoA, resulting from increased glucose metabolism, is associated with increased production. After a 24 h fast, brain acetylcholine levels are lower in rats, levels then can be restored by either refeeding or administering glucose (Kuntscherova, 1972). Messier *et al.* (1990) reviewed the topic and concluded that in resting conditions increased glucose availability has little effect on acetylcholine levels in continuously-fed animals. However, when there is a high demand for acetylcholine, a high availability of glucose increases the rate of synthesis of the transmitter. One situation associated with a high demand for acetylcholine is learning. A drug-induced fall in acetylcholine can be reduced by the administration of glucose (Delezal & Tucek, 1982; Ricny *et al.* 1992). Durkin *et al.* (1992) produced the first direct evidence that raised glucose levels facilitate acetylcholine synthesis, by measuring its release from the rat hippocampus under conditions of increased neuronal activity. In mice, raising glucose levels attenuates the amnaesia induced by the anti-cholinergic drug scopolamine (Stone *et al.* 1988). Taken together these animal studies are consistent with the view that under periods of neuronal activity, raising the glucose supply is associated with an increased synthesis of acetylcholine, that benefits memory.

In summary the eating of breakfast has been found to benefit memory. One of the mechanisms by which breakfast facilitates memory involves the raising of blood glucose. A question for future study is whether breakfasts of different nutritional compositions influence memory to a greater or lesser extent.

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