The Acute Effects of Meals on Cognitive Performance

Caroline R. Mahoney, Holly A. Taylor, and Robin B. Kanarek

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It is well established that poor nutrition, particularly early in life, can have lasting effects on brain functioning and cognitive performance. In contrast, much less is known about the short-term effects of meals on cognitive behavior in well-nourished individuals. Interest in this area of research has primarily stemmed from the desire to improve cognitive performance in either the workplace or classroom, and, consequently, some meals have received more attention than others. However, the results of studies on the effects of meals on cognitive behavior can also increase our understanding of the basic manner in which nutrients affect brain functioning.

This chapter considers how meals may influence cognitive processing in a broad sense. It presents the issues confronted when investigating the effects on meals and cognitive performance and provides a review of experiments that have addressed the consequences of intake of breakfast, lunch, dinner, and snacks on the cognitive performance of individuals across the lifespan.
6.1 **WHY IS IT IMPORTANT TO STUDY THE EFFECTS OF MEALS ON COGNITIVE BEHAVIOR?**

Studying meals is important because it represents the way that people actually eat. Although studies examining the effects of single nutrients on mental performance may be easier to interpret and produce larger effects than studies using mixed meals, results of studies using single nutrients are difficult to frame in the context of normal eating behavior. People do not consume individual nutrients; rather, they eat meals or snacks containing varying amounts of the three energy-containing nutrients — protein, fat, and carbohydrate. However, although it is important to investigate the effects of actual foods on cognitive behavior, studying meals is complicated. First, it is often difficult to create a comparison group or placebo for a meal, short of eating vs. not eating. The lack of a suitable placebo may affect the experience of the participant on several levels as well as create methodological problems. For example, without a placebo, it is impossible to conduct double-blind experiments, leading to the possibility of subject and experimenter bias.

Results of research on the effects of meals on cognitive behavior differ significantly among studies; for example, some experimenters have found effects of meals on behavior whereas others have not. Several explanations exist for these inconsistencies. Test meals, in terms of calories or macronutrient content, cognitive tasks used, and times between meal consumption and testing, differ greatly across experiments. With little consistency in meals or methodology in experimental studies, the variation in results is not surprising.

6.2 **VARIABLES TO CONSIDER WHEN INVESTIGATING THE EFFECTS OF MEALS ON COGNITIVE BEHAVIOR**

6.2.1 **Characteristics of the Meal**

Both the size and macronutrient content of a meal contribute to the way in which the meal influences mental performance. With respect to meal size, children displayed greater improvements on measures of creativity, physical endurance, and mathematical ability when they received a high-energy breakfast as compared to a low-energy breakfast (Wyon et al., 1997). In contrast, other studies have suggested that a large lunch is associated with a greater decline in cognitive performance in the afternoon than is a small meal. Participants’ normal meal habits also must be considered when evaluating the effects of meal size on cognitive behavior. For example, individuals who regularly consume a large lunch are less affected by the consumption of a large meal at lunchtime than those who normally eat a small meal (Craig and Richardson, 1989). The specific macronutrient content of the meal is also important in determining the cognitive effects of the meal. Studies examining the effects of lunch on subsequent behavior have demonstrated that high-protein meals typically lead to increased distractibility, whereas high-carbohydrate meals are associated with slowing of reaction times (Smith et al., 1988).

6.2.2 **Time**

The ways in which a meal affects cognitive performance vary depending on the time of day at which it is consumed. Identical meals eaten in the morning, midday, or evening can have different effects on cognitive behavior. Endogenous biological rhythms may be one explanation for the differential effects of meals on performance. In general, individuals tend to be alert and perform well on cognitive tasks during the early part of the day, whereas in the afternoon many individuals suffer from a decrease in alertness and efficiency (Smith et al., 1988). Real-life measures of attention, such as the frequency of nodding off while driving a car or the potential for a train engineer to miss a warning signal, illustrate that performance typically declines around 2:00 p.m. (Folkard and Monk, 1985). Laboratory investigations examining fluctuations in cognitive behavior...
across the day have also shown that performance efficiency improves until midday, at which time there are reductions in performance on tasks measuring simple reaction times, sustained attention, and ability to perform mathematical problems (Blake, 1967). Later in the day, performance on these tasks again improves. Whether the midday decrement in performance is simply due to endogenous rhythms or due to the consumption of lunch is still not clear. For example, performance on a serial reaction time task was slower in the afternoon than in the morning for subjects, whether they had or had not eaten lunch. In contrast, measures of perceptual discrimination (Craig et al., 1981; Smith and Miles, 1986a) declined during midafternoon in participants who had consumed lunch but not in those who abstained from eating. It is possible that the midday decrement in performance observed on some performance measures may be due to both endogenous rhythms and the consumption of lunch (Smith and Miles, 1986b).

The interval between when a meal is consumed and the time of testing may also affect performance measures. For example, observations made 15 or 30 min after consuming a meal may differ from those obtained 3 h later. In addition, the interval between the test meal and the last meal consumed must be considered. Performance may be quite different following a meal if participants have been previously fasting than if they have recently consumed another meal. These effects may be due to differences in gastric contents, blood glucose levels, or, simply, feelings of satiety.

6.2.3 Personal Characteristics

Age can influence the effects of a meal on performance in a number of ways. Younger children are generally more affected by breakfast consumption than are older children (Mahoney et al., unpublished data). In addition, the negative effects of lunch on cognitive performance increase with age (Spring et al., 1982). Personality also influences the way in which meals affect performance. It has been reported, for example, that following a lunchtime meal, subjects who were less anxious tended to show greater performance impairments than those who were more anxious (Craig et al., 1981).

Finally, nutritional status influences the effects a meal has on performance. It has been repeatedly observed that children who are poorly nourished are more adversely affected by missing breakfast than those who are considered well nourished. For example, breakfast consumption significantly improved performance on measures of verbal fluency, memory, arithmetic performance, and perceptual abilities in nutritionally at-risk children, but had minimal effects in children who were adequately nourished (Pollitt, 1995).

6.3 How Might Meals Affect Cognitive Processes?

One way that meals are thought to affect cognitive function is through the changes in blood glucose concentrations that result from food ingestion (see Chapter 5). Glucose is an essential component for brain metabolism and provides the brain with almost all of its energy (Benton et al., 1996). If the concentration of glucose in the blood becomes too low, the result could range from impairment of mental function to coma or death (Harper, 1957). The synthesis of neurotransmitters essential for fine motor skills and cognitive processes, such as noradrenaline, acetylcholine, and serotonin, is also dependent on glucose metabolism.

There is considerable evidence that even small increases in circulating blood glucose concentration can lead to the enhancement of learning and memory across the lifespan (Gold, 1986, 1995). This enhancement is seen in the form of an inverted-U dose–response curve, with optimal levels of cognitive enhancement typically reported after a glucose load of 25 g (Parsons and Gold, 1992). Glucose-induced improvements in memory do not occur only in those whose blood glucose levels are initially low; rather, they occur irrespective of initial blood glucose level (Benton and Owens, 1993).
Glucose ingestion has been shown to enhance memory for learned material regardless of whether it is administered before the acquisition of new material or recall of the material (Hall et al., 1989; Manning et al., 1990, 1992, 1998; Craft et al., 1992). In addition, glucose improves memory for learned material even when recall is tested 24 h after acquisition (Manning et al., 1992).

It is important to recognize that glucose ingestion does not always lead to improvements in memory. Gonder-Frederick et al. (1987) found no significant differences between individuals given glucose or a placebo on simple memory tests. It appears that glucose enhancement of memory is type specific. For example, Gold (1995) found that glucose ingestion enhanced verbal declarative memory but not implicit memory. He proposed that memory stores are differentially sensitive to blood glucose concentrations, which could account for the selective increase in performance on some but not all memory tasks (Gold, 1995).

Another possible explanation for the effects of food on cognitive performance is that the individual macronutrients consumed within a meal differentially affect cognitive performance (Kaplan et al., 2001; Fischer et al., 2002). A study done by Kaplan et al. (2001) examined this issue. Participants were given a pure protein drink, a pure carbohydrate drink, a pure fat drink, or a nonenergy placebo drink on four separate mornings. Pure dietary protein, carbohydrate, and fat enhanced memory performance 15 min after ingestion, independently of elevations of blood glucose (Kaplan et al., 2001). However, 60 min after ingestion, only the glucose drink was associated with improved memory. In addition, only protein was associated with a decrease in forgetting on a paragraph recall test and only fat and glucose improved performance on the Trails test. In a study examining the effects of the carbohydrate-to-protein ratio in a morning meal on cognitive performance in younger adults, Fischer et al. (2002) found that a protein-rich or a balanced meal resulted in better cognitive performance than a carbohydrate-rich meal. Thus, though energy ingestion may influence some areas of cognitive performance, each macronutrient may have independent effects on cognitive processes. These differences may be the result of varying neurotransmitter synthesis.

The ingestion of a meal can influence the synthesis of brain neurotransmitters (Wurtman, 1982). For example, a meal rich in carbohydrates increases the amount of brain tryptophan, which results in an increase in the synthesis of serotonin (Lieberman et al., 1986). The increase in brain tryptophan is a result of insulin secretion following ingestion of carbohydrates. Insulin causes most of the other amino acids to leave the bloodstream and be taken up into the muscle, whereas tryptophan remains in the blood (Spring, 1986). Consequently, the flow of tryptophan into the brain is increased as the competition with other amino acids for transport across the blood-brain barrier is decreased. The increase of tryptophan to the brain causes an increase in the synthesis and release of serotonin. This effect can easily be reversed, however, if a meal contains even a small amount of protein. For example, when tested in rats, a meal containing only 6% protein reduced brain tryptophan levels (Glaeser et al., 1983).

Consumption of a protein-rich meal leads to an increase in the level of brain tyrosine, which results in an increased synthesis of neurotransmitters such as dopamine and norepinephrine (Lieberman et al., 1986). Because a protein-rich meal contains both tryptophan and tyrosine, it seems likely that this would lead to an increase of both brain tryptophan and tyrosine levels. However, because tryptophan is the least abundant amino acid in a protein-rich meal and all amino acids compete for the same transport molecules to cross the blood-brain barrier, the ingestion of a high-protein meal decreases the amount of tryptophan available to the brain (Wurtman, 1986). On the other hand, the plasma ratio of tyrosine increases after a protein-containing meal, and therefore more tyrosine is available for uptake into the brain. Thus, the synthesis of dopamine and norepinephrine increases after a protein-rich meal, whereas the synthesis of serotonin decreases.

The altered levels of neurotransmitters produced by food consumption may in turn exact changes in mood and cognitive performance. For example, Lieberman et al. (1986) examined the effects of tryptophan and tyrosine on mood, reaction time, and motor performance. They found that when participants consumed a tryptophan pill, they rated themselves as being less alert, having less vigor, and being more fatigued compared to when they consumed a tyrosine pill or a placebo. In addition,
participants had slower reaction times after tryptophan than after tyrosine (Lieberman et al. 1986). Several studies looking at the effects of carbohydrate-rich meals compared to protein-rich meals have found similar results: a carbohydrate-rich meal increased drowsiness and calmness compared to a protein-rich meal (Spring et al., 1987).

6.4 BREAKFAST

Breakfast is often described as the most important meal of the day. Because breakfast follows the longest period of fasting, skipping breakfast could result in a decrease in the amount of nutrient availability to the brain and ultimately lead to a decline in cognitive performance (Pollitt, 1995). Despite this, several studies have found that nearly 25 to 60% of children in the U.S. are sent to school each day with nothing to eat between their evening meal at approximately 6:30 p.m. and lunch the next day (Siega-Riz, 1998; Mahoney et al., unpublished data). These findings have led researchers to address the question of how a prolonged fast affects a child’s ability to perform in school.

6.4.1 CHILDREN

Results of numerous experiments suggest that missing breakfast can have detrimental effects on cognitive performance (Pollitt, 1995; Pollitt et al., 1983; Wesnes et al., 2003). In a study assessing the effects of skipping breakfast on problem-solving ability in young well-nourished boys, Pollitt et al. (1983) reported that the boys did worse in late-morning tests of problem-solving abilities when they had skipped breakfast than when they had consumed it. Skipping breakfast has also been linked to impairments in attention and episodic memory, which increase in severity over the morning (Wesnes et al., 2003).

The interest in the effects of breakfast on cognitive performance led to several investigations of the National School Breakfast Program. An early study in Los Angeles, CA, looked at children in Grades 3 to 6 in two schools (Lieberman et al., 1976). One school was offered free breakfast and the other was not. Performance measures included school attendance and arithmetic and reading scores. There was no difference in the performance of children who did and did not participate in the school breakfast program. However, the children were not randomly assigned to breakfast or control groups, so that children who did not participate in the school breakfast program were not suffering from the lack of nutrients and were consuming diets as adequate as those in the breakfast program.

More recent studies have indicated that consumption of a school breakfast can have beneficial effects on academic performance. For example, in Lawrence, MA, children in Grades 3 to 6 who participated in a school breakfast program on at least 60% of the school days performed better on a standardized test and had lower school tardiness rates than children who did not partake of the breakfast program. Similarly, research conducted in Philadelphia and Baltimore found that across the school year, children who regularly ate a school-supplied breakfast displayed significantly greater improvements in math scores and significantly greater decreases in rates of school absences and tardiness than those who rarely ate breakfast (Murphy et al., 1998).

Studies in other countries as well as the U.S. provide evidence that breakfast consumption can have positive outcomes on academic performance. In Israel, Vaisman et al. (1996) reported that children who ate a school breakfast that contained 30 g of sugared corn flakes and 200 ml of 3% milk performed better on memory and learning tasks than children who did not eat breakfast or who ate at home. Similarly, studies from Spain demonstrated that children who regularly consumed an adequate breakfast (i.e., more than 20% of total daily caloric intake) scored higher on a test of logical reasoning than did children who consumed a less adequate meal (Lopez-Sobaler et al., 2003). Research in Jamaica demonstrated that consumption of a standard government breakfast positively affected school attendance and arithmetic performance in undernourished children. Other
studies, also done in Jamaica, showed that children’s nutritional status must be considered when investigating the effect of breakfast on academic skills. For example, Simeon and Grantham-McGregor (1989) found that breakfast intake improved measures of verbal fluency, memory, arithmetic performance, and perceptual abilities in children who were considered nutritionally at risk. In contrast, breakfast did not affect cognitive performance in well-nourished children.

### 6.4.2 Adults

Consumption of breakfast has positive effects on cognitive behavior in adults as well as children. In studies conducted more than 50 years ago, Tuttle et al. (1952) compared effects of a heavy (800 kcal), light (400 kcal) or no breakfast or just coffee on simple and choice reaction times. Results indicated that subjects in the no-breakfast group took longer to respond than subjects in the other three groups. However, the no-breakfast group was the only group that did not receive coffee. Thus, it is possible that the observed effects were due to the caffeine in the coffee rather than the meal vs. no meal manipulation. Caffeine itself can enhance performance on vigilance tasks, increase alertness, and improve complex behavior such as that required for driving a car or flying a plane (Brice and Smith, 2001). Most consistently, caffeine seems to improve performance on tasks that are boring or require sustained attention, especially under conditions of sleep deprivation (Committee on Military Nutrition Research, 2001). Thus, the inclusion of caffeine in a test meal could confound results of measures of cognitive performance if the caffeine is not present in the control condition also.

More recent studies controlling for the presence of caffeine have also demonstrated the beneficial effects of breakfast consumption in adults. For example, Benton and Sargent (1992) found that university students (mean age 21 years) took significantly less time to recall a list of words and to finish a spatial memory task when they had eaten breakfast than when they had not. Similarly, Smith et al. (1994a) reported that subjects recalled more words in a test of free recall and made fewer errors in a test of recognition memory when they had eaten breakfast cereal than when they had not had breakfast.

### 6.4.3 Elderly

The elderly, like the young, may be particularly sensitive to the effects of nutrition on cognitive behavior. Elderly individuals, as a result of disease, a decreasing ability or desire to prepare meals, or problems associated with a reduction in income, are more likely to suffer nutritional deficiencies than their younger counterparts. Thus, breakfast intake may have greater effects on cognitive performance in older than in younger individuals. Studies done in the early 1950s, however, do not support this hypothesis (Tuttle et al., 1952, 1953). Cognitive performance, as measured by a choice reaction task, was similar in elderly adults, aged 60 to 83 years, given no breakfast or one of two isocaloric breakfasts that contained either 25 g protein, 37 g fat, and 80 g carbohydrate or 25 g protein, 28 g fat, and 100 g carbohydrate (Tuttle et al., 1952). In a follow-up to the preceding study, Tuttle et al. (1953) compared the effect of a heavier breakfast (998 kcal) vs. two more basic breakfasts (744 to 750 kcal) on reaction times in adults aged 60 to 84 years. Each participant again participated in all three conditions. In this study, subjects had slower reaction times when they had consumed the heavier breakfast than when they had consumed either of the two less-caloric breakfasts.

Although the early studies cited previously suggest that breakfast intake does not play an important role in mediating cognitive behavior in the elderly, more recent studies counter this suggestion. Elderly adults, aged 60 to 79 years, who ate breakfast cereal every day performed better on a national adult reading test than those who either ate breakfast every day but not always cereal or infrequently consumed breakfast. These results, although indicating that breakfast consumption improves intellectual functioning, can also be interpreted as demonstrating that healthier, more cognitively aware elderly are more likely to consume breakfast than their less fortunate counterparts.
6.4.4 Breakfast Type

As detailed in the previous sections, breakfast intake is not consistently associated with improvements in cognitive performance (Table 6.1). Differences in the quantity and quality of foods consumed at breakfast may account, in part, for these mixed results. With respect to the quantity of food consumed at breakfast, Wyon et al. (1997) reported that school-aged children did better on tests of creativity, physical endurance, and mathematical ability when they had consumed a high-energy breakfast (bread rolls, light margarine, soft processed cheese, a boiled ham slice, milk, cornflakes, an apple, and orange juice) than when they had consumed a low-energy breakfast (bread rolls, light margarine, diet raspberry jam, and a diet orange cordial). Similarly, Michaud et al. (1991) showed that a high-energy breakfast, as a compared to a low-energy breakfast, improves short-term memory in young adults. Although these studies suggest that consumption of a large breakfast may have beneficial effects on cognitive behavior relative to a small breakfast, they do not take into account the role of the participants’ normal patterns of food intake on the dependent variables. With respect to this issue, studies have found that individuals did worse on cognitive tests when the experimental breakfast was either significantly larger or smaller than the breakfast they normally consumed.

The macronutrient content of a morning meal must also be considered when evaluating the consequences of the meal on cognitive behavior. For example, intake of pure protein, fat, or carbohydrate following an overnight fast improved performance on a short-term memory task in healthy elderly subjects; intake of each of the macronutrients affected cognitive behavior in a unique manner. More specifically, carbohydrate intake was associated with more sustained improvement on the memory task than were protein or fat intakes, whereas protein, but not carbohydrate or fat intake, decreased the rate of forgetting on a paragraph recall test (Kaplan et al., 2001). Further support for the importance of the nutrient quality of breakfast in determining subsequent behavior comes from a study by Lloyd et al. (1996), who reported that mood, but not cognitive performance, was improved when subjects consumed a low-fat, high-carbohydrate breakfast relative to either a medium-fat, medium-carbohydrate breakfast, a high-fat, low-carbohydrate breakfast, or no breakfast (Lloyd et al., 1994).

In two recent studies, Mahoney and coworkers (unpublished data) examined the effects of two common breakfast foods, instant oatmeal and ready-to-eat cereal, vs. no breakfast on cognitive performance in elementary-school children. The two cereals were similar in calories but differed in their macronutrient composition, processing characteristics, effects on digestion and metabolism, and glycemic index. More specifically, each cereal contained the same amount and type of sugar, but the oatmeal contained approximately three times the protein and fiber of the ready-to-eat cereal. Each child participated in all conditions separated by a week. In the first experiment, 9- to 11-year-old boys and girls did significantly better on a spatial memory task presented 1 h after eating instant oatmeal than after having no breakfast. In addition, after consuming either breakfast cereal, children more accurately copied a complex visual display than when they had not consumed breakfast. Short-term memory was influenced by breakfast intervention and sex: consumption of the instant oatmeal improved performance for girls compared to when they consumed the ready-to-eat cereal breakfast or no breakfast, but for boys performance did not differ based on breakfast intervention. In the second experiment, 6- to 8-year-old children performed better on a spatial memory task when they had oatmeal breakfast than when they did not. There were no differences in performance between the ready-to-eat cereal condition and the no breakfast condition. Again, as with the older children, analysis of the short-term memory task revealed that girls recalled more when they had oatmeal than in the other two conditions. In addition, performance on an auditory attention task was best after consuming oatmeal, followed by no-breakfast, and finally ready-to-eat cereal.
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<td>No difference</td>
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<td>Lopez et al. (1993)</td>
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Effects of Breakfast on Cognitive Performance

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<td>Tuttle et al.</td>
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<td>79 years</td>
<td>habits</td>
<td>(1) Breakfast cereal everyday</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(2) Breakfast everyday but not always cereal</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(3) Irregular breakfast eaters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tuttle et al.</td>
<td>Elderly, 60 to</td>
<td>Breakfast vs. no</td>
<td>Bacon, egg, milk, toast, and fruit: 750 kcal, 25 g protein, 37 g fat, 80 g carbohydrate</td>
<td>Choice reaction time</td>
<td>No effect of breakfast</td>
</tr>
<tr>
<td>(1952)</td>
<td>83 years</td>
<td>breakfast</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tuttle et al.</td>
<td>Elderly, 60 to</td>
<td>Breakfast vs. no</td>
<td>Bacon, egg, milk, toast, and fruit: 744 kcal, 25 g protein, 37 g fat, 78 g carbohydrate</td>
<td>Choice reaction time</td>
<td>Slower reaction times following the heavier breakfast than the two basic breakfasts</td>
</tr>
<tr>
<td>(1953)</td>
<td>84 years</td>
<td>breakfast</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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6.4.5 Conclusion

Taken together, the results of the preceding studies provide strong evidence for the beneficial effects of breakfast on cognitive behavior across the lifespan. Although there are some differences in exactly what tasks were affected, in almost all the studies breakfast intake led to improvements in cognitive performance. These results have practical and political implications. A substantial number of children in the U.S. go to school every day without eating breakfast. Over time, the small impairments in cognitive performance that could result from the lack of a morning meal could have substantial consequences on academic achievement and later success in life. Thus, it is important for individuals to regularly consume breakfast and for the government to maintain school breakfast programs.

6.5 Afternoon Meal

In contrast to breakfast, consumption of lunch has been most often reported to impair mental performance and negatively alter mood state. In real-life situations, individuals generally perform more poorly on mental tasks after lunch than in the morning or late afternoon hours. For example, falling asleep while driving, lapses of attention by locomotive engineers, and errors by shift workers are most pronounced in the midafternoon hours (Craig, 1986). Similarly, studies conducted in the laboratory have found that a drop in performance of mental tasks often is reported approximately 1 h after consuming lunch and may take several hours to return to the prelunch state. The drop in performance is usually found in measures of speed, accuracy, and sustained attention (Smith and Miles, 1986a, 1986b). Mood has also been shown to differ after consuming lunch (Smith et al., 1988, 1991), with self-ratings of more feeble, bored, lethargic, mentally slow, dreamy, and clumsy after consuming lunch compared to before. The decrease in mental ability and mood that occurs following intake of a midday meal has been termed the postlunch dip.

It has been suggested that the effects of lunch intake on cognitive behavior may be primarily the results of circadian rhythms in mental alertness (Hildebrant et al., 1974). In support of this suggestion, midafternoon decrements in performance have been observed on some tasks whether or not lunch was consumed. However, for other tasks, mental abilities at midday are impaired to a greater degree in individuals who have consumed lunch than in those who have not, indicating that food intake does contribute to the postlunch dip (Craig, 1981; Smith and Miles, 1986a, 1986b; Wells et al., 1998).

6.5.1 Children

Studies examining the effect of lunch on cognitive performance in children have been primarily limited to those evaluating the merit of the school lunch program. Although many of these studies suggest that consumption of a school-supplied meal improves nutritional status, weight for age, height for age (Rewal, 1981), and the behavior of children in the classroom compared to when they are hungry (Read, 1973), the general consensus is that there is little effect on school achievement (Gietzen and Vermeerch, 1980). Unfortunately, because of the nature of these studies, control groups are often not possible or inappropriately matched and measures generally consist of course grades or performance on standardized tests. These measures are in essence achievement tests and thus not appropriate for evaluating the effects of lunch vs. no lunch on cognitive performance. In addition, many of these studies are confounded in that they do not control for socioeconomic status, parental education, number of siblings, number of parents present in the household, parental participation in the child’s education, nutritional status, and regular meal habits, as all these variables may influence performance either independently or as a function of the meal consumed.
6.5.2 Adults

Studies examining the effects of the noontime meal on performance in adults have been conducted both in the laboratory (Smith and Miles, 1986a, 1986b) and work settings (Hildebrant et al., 1974). In general, the research indicates that the consumption of lunch leads to a decline in performance. These findings may suggest potential costs of consuming a midday meal with regard to efficiency and safety in work, academic, or military environments.

Craig et al. (1981) examined whether lunch affected the efficiency of perceptual discrimination. This measure was chosen because of the significance to many work-related tasks such as radar monitoring, product inspection, and x-ray examination, as well as the role it may play in safety when warning signals are presented. Participants performed this task before and after either eating a three-course lunch and or having no lunch. Performance of the participants who consumed lunch declined, whereas performance of those who abstained from lunch did not. The authors conclude that consumption of lunch is an important precursor for the postlunch dip in performance. In addition, they state that the magnitude of the effect found in the present study is comparable to performance after the deprivation of a complete night of sleep (Craig et al., 1981).

Smith and Miles (1986a) also examined whether a postlunch change in performance was observed only in participants who consumed lunch or whether it was observed irrespective of lunch consumption. Participants were either assigned to a lunch condition, which consisted of a three-course meal at the dining hall or no lunch. However, participants in the lunch condition were allowed to eat what they wanted and therefore the size and content of the meals varied. In addition, individuals in the lunch condition were allowed to drink coffee and tea and smoke if they desired following the meal. Participants were tested both during the late morning and early afternoon on a five-choice serial reaction time task and the Stroop task. Results of the study revealed that participants who ate lunch had slower reaction times on the reaction time task, but measures on the Stroop task were not affected by consuming lunch. This study was problematic for several reasons, however. First, the lunch subjects were allowed to consume caffeine and nicotine if they desired before testing and these substances may have affected performance. In addition, nearly all the participants reported that the size of the lunch they ate was larger than their normal lunch. Thus, as previous research has shown, decrements in performance may have occurred due to the deviation from normal meal habits.

Smith and Miles (1986b) also conducted a study to examine the effects of a midafternoon meal on a vigilance task. Again, participants either had a three-course meal at the cafeteria or abstained from lunch until after testing. The content and the size of the meal for the lunch group were not controlled and participants were all allowed to have coffee, tea, or cigarettes before testing. Participants completed a dual task, which consisted of a detection of repeated numbers task and an estimation task. In the detection task, subjects were required to watch sequences of three-digit numbers, each differing from the previous number by one digit, and identify when a number appeared that was identical to the number preceding it. At the same time this task was being completed, participants were also scanning a continuous stream of single letters and digits and making estimations of the percentage of letters presented at specified time intervals. Results from this study revealed that subjects who ate lunch detected fewer targets than those who did not consume lunch. However, participants who had lunch did not show impairment in performance on the estimation task. Results also showed that participants who did not consume lunch performed worse in the afternoon than in the morning session. Thus, the consumption of lunch may affect some aspects of cognitive performance, but there also appears to be an endogenous component.

6.5.3 Lunch Type

Another important issue is the effect of the composition of the meal on performance and mood. In many of the studies reviewed, the participants were required to eat a meal that differed from their
normal meal habit. It is possible that some of the effects of meals on performance were due to the novelty of the test meals or the departure from their normal meal habits. To examine this notion, Craig and Richardson (1989) looked at the interaction between normal lunch habit and experimental lunch size. Participants were either classified as light eaters (less than 300 kcal) or heavy eaters (more than 1200 kcal) and were tested in both a light test meal condition (sandwich consisting of 260 kcal) and a heavy test meal condition (three-course meal consisting of 1300 kcal) whose protein to carbohydrate ratios were 2:3. They hypothesized that there were four possible outcomes of the experiment: (1) there would be no difference in performance; (2) performance would differ by time of day but not by lunch type, and thus the differences would be endogenous; (3) changes depend on the experimental meal but not the normal meal habit, and thus the differences would be purely exogenous; and (4) changes depend on both the experimental meal and habitual meal size, and thus a combination of endogenous and exogenous processes occur (Craig and Richardson, 1989). Results of this study showed that the number of errors on a letter cancellation task increased after a big lunch and decreased after a small lunch. In addition, the extent of change was greater if the meal was different from that normally consumed; for example, light eaters who consumed a big lunch performed the worst whereas heavy eaters consuming a small lunch performed the best.

As with many laboratory studies on the effects of meals and performance, participants are often asked to consume a meal that is different from what they would normally consume. Thus, it is possible that the effects observed in many studies are influenced by a combination of the normal eating habits of the participants and the novelty of the test meals. Several studies found that the performance of participants is affected by the interaction of the normal eating habits of the participants and the test meals provided at both breakfast and lunch (Craig et al., 1981; Mahoney et al., unpublished data).

6.6 SNACKING

Snacking contributes to a significant amount of our daily food intake. This is especially true for young children and adolescents, for whom snacks may account for up to one third of the daily calories. There is a popular belief that snacking is a negative habit, especially when sugary snacks are consumed. However, limited research on the effects of snacking on cognitive performance suggests that between-meal food intake may actually be beneficial for learning and memory.

6.6.1 LATE-MORNING SNACK

Research to date suggests that consuming a late-morning snack can improve subsequent cognitive performance. In the first study, performance on two tasks measuring concentration abilities was compared when office workers either had or had not consumed a late-morning snack (two ham sandwiches and hot tea; Hutchinson, 1954). Cognitive tasks consisted of a digit-symbol matching test and a task that required participants to cross out six-figure numbers, of which there were several columns, containing certain pairs of digits. When the office workers had a late-morning snack, performance on the digit-symbol matching test was significantly better than when they did not. There were, however, several confounding variables in this study. First, the caffeine in the tea could have affected some aspects of performance. In addition, there were no controls for what the participants ate for breakfast the morning of testing or when they ate. Finally, the duration of cognitive testing was short. It is possible that the second measure of concentration may also have shown significant differences between snack conditions if the testing session was longer.

A follow-up study was conducted, which alleviated some of the previous confounds (Hutchinson, 1954). The procedures remained the same with two exceptions. Tea was replaced with a fruit drink and a longer testing session was used. Results showed that when the participants had a late-morning snack, performance was significantly better than when they did not. The authors
concluded that the ability to concentrate, when the stomach can reasonably be assumed to be empty, is improved after consuming a small amount of food (Hutchinson, 1954). However, in addition to the concerns mentioned previously, one more concern exists. The morning snack was given at 11:50 a.m. and the size of the snack could be consistent with a normal lunch. Although it was noted that in this population lunch often was consumed after 1:00 p.m., both the size of the snack and the time of ingestion raise concerns on whether these studies really examined the effects of a late-morning snack or a light afternoon meal.

In a more recent study, Benton et al. (2001) addressed the question of whether a late-morning snack would interact with breakfast intake in determining psychological functioning. Young women were given breakfasts containing either 10 or 50 g of carbohydrate. After 1.5 h, half the women were given a further 25 g of carbohydrate in the form of corn flakes (snack) and the other half no snack. Results indicated that performance on a verbal memory task was not influenced by breakfast consumption but was positively affected by snack intake.

6.6.2 Afternoon Snacks

By using a paradigm similar to that described for late-morning snacks, early research investigating the effects of a late-afternoon snack on measures of concentration found no differences in performance as a function of food intake. Workers either consumed a snack from 3:50 to 4:00 p.m. or did not and then completed two short tests of concentration at 4:10 p.m. The snack consisted of a plate of two ham sandwiches, cut into eight quarters, with a total weight of 5 oz, and a 9-oz cup of hot tea. Participants were allowed to eat as many of the eight sandwich quarters as they desired. Cognitive tasks consisted of a digit-symbol matching test and a task that required participants to cross out six-figure numbers, of which there were several columns, containing certain pairs of digits. Results showed that an afternoon snack had no effect on performance during either task. However, this study was problematic for several reasons. First, there were no controls for what the participants ate for lunch on the day of testing or when they ate lunch. It is possible that a considerable number of subjects may have still had food in their stomachs as a result of their afternoon meal. In addition, testing took place 10 min after snack consumption and lasted only 3 min. It is possible that the experimenters did not leave enough time in between the snack and testing to allow the levels of blood glucose in the snack condition to rise. Furthermore, the tests measured a relatively small window of concentration time (1.5 min/test). It is possible that this window was not large enough to detect significant differences in performance. Finally, the snack condition was confounded with the consumption of caffeine from the tea, as previous research shows that caffeine itself can affect some aspects of performance (Smith et al., 1994a, 1994b; Committee on Military Nutrition Research, 2001).

More recent studies looking at the effect of an afternoon snack lack the confounds mentioned in the previous study. Kanarek and Swinney (1990) looked at the effect of a late-afternoon snack on the cognitive performance of college-aged men.

Results of this study suggest that ingestion of a calorie-rich snack enhances performance. The snack consisted of an 8-oz fruit-flavored yogurt or a noncaloric diet soft drink without caffeine. College students were fed breakfast and lunch in the laboratory and participated in each of four conditions separated by a week. These conditions were (1) breakfast, lunch, and yogurt snack; (2) breakfast, no lunch, and yogurt snack; (3) breakfast, lunch, and diet soda (noncaloric snack with no caffeine); and (4) breakfast, no lunch, and diet soda. Fifteen minutes after consuming the snack, participants completed tests of memory (digit span), arithmetic reasoning, reading, and attention. There was a practice session for the tasks before the start of the experiment. Results showed that participants recalled more digits during the backward digit span task and responded more quickly when making correct responses during the attention task after the calorie-rich snack than the noncaloric snack. In addition, participants correctly solved more problems in the arithmetic reasoning task and had significantly faster reading times after having the yogurt snack compared to the soft drink.
6.6.3 Confectionery Snacks

There is a popular cultural belief that consumption of sugary snacks causes hyperactive behavior in children. More specifically, people believe that as a result of ingesting a sugar snack, children will suffer from a decreased ability to maintain attention, which hinders abilities to carry out cognitive tasks. Hyperactivity includes such components as failure to follow through on tasks, inability to sustain activities for an appropriate period of time, and difficulties in organizing and completing work (Kanarek, 1996). King (1996) suggests that sugar does not affect the behavior or cognitive performance in children. Instead, it may be because activities surrounding ingestion of sugar, such as trick-or-treating, produce excited states in children. Parents then associate the excited state with sugar intake. Thus, parental expectancies may have some impact on how they perceive behavior.

Hoover and Milich (1994) tested the hypothesis that the commonly observed hyperactivity in children after sugar consumption may actually be due to the mother’s expectancies rather than the sugar itself. Mothers of thirty-five 5- to 7-year-old boys were told either that their child received a large dose of sugar or that their child received a sugar-free placebo. In actuality, all the children received the sugar-free placebo. The children in the “sugar” condition were rated significantly more hyperactive by their mothers than the children in the “nonsugar” condition (Hoover and Milich, 1994). This study shows that despite the lack of evidence to support the belief that sugar causes hyperactivity in children, the expectancies held by the parents may actually color the way they interpret their own child’s behavior. It appears, because there is no evidence that sugar alone can turn a normal child into a hyperactive child, that any adverse effect of sugar is by no means as severe or as prevalent as uncontrolled observation and opinion would suggest (Kinsbourne, 1994).

Wolraich et al. (1994) conducted several studies that looked at the effects of sugar on behavior and cognitive tasks in preschool and school-age children. Children were provided with a special diet by the experimenters for 3 weeks containing varying amounts of sugar and artificial sweeteners. Recent studies looking at the effect of an afternoon confectionery snack indicate that ingestion of a confectionery snack may actually improve several aspects of cognitive performance. Kanarek and Swinney (1990) looked at the effect of a late-afternoon snack on the cognitive performance of college-aged men. College students were all fed breakfast in the laboratory and then either lunch or no lunch and a confectionery snack or noncaloric snack. Fifteen minutes after consuming the snack, participants completed tests of memory, arithmetic reasoning, reading, and attention. Results showed that participants performed better on a memory task and responded more quickly when making correct responses during the attention task after the confectionery snack than the noncaloric snack (Kanarek and Swinney, 1990). No significant differences were found in measures of reading time or arithmetic reasoning.

Three studies conducted by Busch et al. (2002) examined the effects of a confectionery snack on cognitive performance. In the first experiment, 38 male undergraduates ate breakfast and lunch in the laboratory and then came back in the late afternoon for a snack. Fifteen minutes after consuming the snack, they participated in a dual learning task. The snack consisted of either 50 g of a confectionery product or one cup of an artificially sweetened drink. Each student participated in both conditions, separated by a week. Results showed that when participants consumed the confectionery product, they correctly placed more country names on a map, as well as left fewer countries blank, during long-term recall on the primary spatial learning task. However, with regard to the secondary attention task, when consuming the placebo participants had a higher hit rate as well as a lower miss rate (unpublished data).

A second experiment looked at the performance of thirty-eight boys, age 9–11 yrs, on a dual task in the afternoon after ingestion of either 25 g of a confectionery product or half a cup of an artificially sweetened beverage. Unlike the first experiment, children received either the confectionery product or the artificially sweetened beverage. In addition to the dual task, children also
completed a vigilance attention task. Results showed that the children who had consumed the confectionery snack placed more items correctly on a map as well as left fewer countries blank in short-term and long-term memory recall of the spatial learning task. In contrast with the first experiment, the children who consumed the confectionery snack had a higher hit rate and a lower miss rate for a secondary attention task than children who consumed the placebo. However, when tested on a separate vigilance attention task, the children who consumed the placebo performed better (unpublished data).

### 6.7 EVENING MEAL

To date, there is very limited data examining the effect of an evening meal on cognitive performance. This may be because the evening meal is often consumed at home and does not impede on performance at work or in the classroom. However, this is not altogether true because both children and young adults often study for exams or complete homework after the evening meal. Thus, there is a need for additional research.

In studies on evening meals, Smith et al. (1994) examined the effects of evening meals on cognitive performance in college students. Forty-eight male and female undergraduates either ate a 1200- to 1500-kcal meal between 6:00 and 6:45 p.m. or did not eat. Within those conditions, participants had 150 ml of decaffeinated coffee either with or without a caffeine tablet mixed in. Subjects performed a battery of cognitive tasks an hour before the meal and 90 and 180 min after the start of the meal. The cognitive tasks consisted of free recall, vigilance attention, logical reasoning, simple reaction time, a five-choice serial response task, and delayed recognition memory. Results show that participants who had an evening meal completed more sentences during the logical reasoning task than those who did not have an evening meal. In addition, they reported feeling stronger, more interested, and more proficient than participants who did not consume a meal. However, there were no effects of meal on any of the other tasks. The authors conclude that when a meal of similar quality is consumed in the evening, it has very different effects on performance than when it is consumed as an afternoon meal (Smith et al., 1994b). Although time of day may mediate the effects of a meal on some areas of cognitive performance, note that the authors did not control for what the subjects had consumed earlier that day. Subjects were asked not to eat or drink anything an hour before testing, but if they had a late lunch or a late-afternoon snack, it is possible that some participants may have still had food in their stomach even if they were in the no-meal group.

### 6.8 SUMMARY

The consumption of a meal produces acute effects on some types of cognitive processing in well-nourished children and adults. These effects depend on many variables, such as age, sex, time of testing, size of meal, energy and macronutrient content of meal, normal meal habits of participants, and types of tasks used.

In general, consuming breakfast improves performance on several types of cognitive measures. The types of tasks that tend to be most affected are those assessing short-term memory, vigilance attention, arithmetic performance, and problem solving. The type of breakfast consumed may also affect cognition: a high-energy breakfast improves performance compared to a low-energy breakfast on measures of creativity, physical endurance, concentration, short-term memory, and mathematical addition. Finally, foods that differ in the amount of protein, fiber, or processing characteristics may affect cognitive processing differently.

The consumption of lunch is usually followed by a decrease in performance on measures of sustained attention and alertness. However, there is no clear consensus on whether this reported dip is because of consuming a meal or simply the time of day. In addition, the extent of the dip
depends on characteristics of the person eating the meal, size of meal, and types of task tested. In terms of personality, subjects who are more anxious tend to show lesser performance impairments after consuming lunch compared with those who are less anxious (Craig et al., 1981). With regard to the size of the meal, a larger meal tends to produce a larger decline in performance compared to a smaller meal, and participants’ normal meal habits also interact with the type of meal consumed — participants who regularly consume a large meal do not experience decrements to the same extent as those who normally eat a small meal (Craig et al., 1981). In addition, the effects on performance observed after lunch may increase with age (Spring et al., 1982). Finally, the macronutrient composition of the meal also influences performance: high-protein meals lead to increased distractibility and high-carbohydrate meals lead to slowing of reaction times (Smith et al., 1988).

While the postlunch dip in performance tends to peak about an hour after meal consumption and persist for several hours thereafter, the consumption of an afternoon snack alleviates performance decrements produced by the consumption of lunch. In addition, the consumption of caffeine, either with a meal or alone, produces improvements in performance on tasks such as sustained attention.

Finally, the limited research looking at the consumption of an evening meal suggests that when an evening meal is consumed, performance on a logical reasoning task is improved. In addition, subject feelings of strength, proficiency, and interest are greater after consuming an evening meal.

Although there is not a clear consensus of how mixed meals affect performance, several mechanisms have been considered, including increases in the level of blood glucose and individual effects of macronutrients on neurotransmitter synthesis. Although it is hard to determine how macronutrients affect performance when studied in mixed meals rather than tests of single nutrients, mixed-meal studies are valuable in that represent the way people normally eat.

REFERENCES


