**Christian Perspectives in Education**
**Send out your light and your truth! Let them guide me. Psalm 43:3**

Volume 5 | Issue 1

11-28-2012

# The Relationship of Food and Academic Performance: A Preliminary Examination of the Factors of Nutritional Neuroscience, Malnutrition, and Diet Adequacy

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Adequate and sufficient healthy intake of food is essential to brain function (Bloom, 2009; Dauncey, 2009; Kazal, 2002; Shariff, Bond, & Johnson, 2000). Moreover, maximizing brain function is a prime factor in seizing appropriate cognitive capability – for example, ability to focus, comprehension, evaluation, and application – in learning (Kretchmer, Beard, Carlson, 1996; Schmitt, 2010).

This article addresses three aspects related to the food-learning relationship, including offering (1) a précis of the nutritional needs of the brain by analyzing research from cognitive neuroscience and healthcare fields; (2) an exploration malnutrition in terms of both over- and under-nutrition, and a discussion of the implications of malnutrition at different stages in development; and (3) a consideration of the effect of diet quality on academic achievement. Finally, a synthesis of these three aspects, a discussion of related learning theory and current debate, and practical implications for educational settings is tendered.

The topic is particularly relevant to Christian educators and others who wish to gain an interdisciplinary, sympathetic perspective on how basic human habits and behavior (food ingestion) affect the educational enterprise. All aspects of the human experience, which include physical, emotional, social, moral, and religious dimensions, are to be considered as Christian educators seek a holistic view of life.

## Defining Terms

Nutrition is the central variable in this discussion, so a basic understanding of several dietetic terms is essential. First, *malnutrition* is an imbalance between nutrients the body needs and those the body receives. Malnutrition can exist as *undernutrition,* which is a general and long-term deficiency of calories, or as its opposite, *overnutrition*. Though people experiencing overnutrition consume more than enough calories, they are often deficient in various nutrients, due often to diets that are comprised of nutrient-poor and energy-dense foods such as sugary soft drinks and fast-food items (Taras & Potts-Datema, 2005).

To study malnutrition, *diet quality* – an examination of the intake of nutrients, food groups, or a combination of both – is taken into consideration (Florence, Asbridge, & Veugelers, 2008). Diet Quality Indexes are used to examine nutrient adequacy and diet quality according to current dietary guidelines (Fungwe, Guenther, Juan, Hiza, & Lino, 2009; Kim, Haines, Siega-Riz, & Popkin, 2003). Finally, *nutritional neuroscience* is the study of the effects of food products on behavior and brain function (Dauncey, 2009). [1]

[1] For a more in-depth study in these topics, see the following seminal works: Blackman & Kvasta (2010). *Nutrition psychology: Improving dietary adherence*, Jones & Bartlett; Contento (2011). *Nutrition education: Linking research, theory, and practice*, Jones & Bartlett; Jukes, Drake, & Bundy (2008). *School health, nutrition and*

## Paucity of Research on the Effects of Food in Childhood Learning

Most might share these theoretical assumptions as a starting point for the relationship of food and learning: (1) that consistent consumption of an adequate, high-quality diet improves academic performance; (2) that a higher-quality diet corresponds to higher academic performance; and (3) that malnutrition contributes to the low levels of academic performance prevalent among children living in poverty. Yet, while there may be a consensus that food is essential to learning, there is little empirical research that examines the exact relationship between children's overall diet and academic achievement. Neither are the results conclusive in determining the precise nature and degree of the food-learning relationship (Gomez-Pinilla, 2008; Hollar, Messiah, Lopez-Mitnik, Hollar, Almon, & Agatston, 2010).

Controversy exists regarding the specific foods that comprise an adequate diet, the effect of food intake throughout development on immediate and ensuing academic outcomes, and the nature and extent of the relationship between nutrition and academic performance. The controversy seems to exist because of divergent conclusions that have emerged from various studies. Some of these studies may have such mixed results because of the research design difficulties. Another likely explanation for lack of concrete knowledge about the causal effects of nutrition on the brain and academic achievement is that designing randomized control trials (RCTs) to study the effects of specific nutritional aspects is difficult (de Jager & Kovatcheva, 2010; Paus, 2010; Schmitt, 2010). Many RCTs either are too short in duration, too narrow in focus, or too small in sample size, or utilize measurement tools that are too unreliable and subjective to generalize about nutrition's long-term effects on broad populations.

Studies using other methods often have complex confounding variables that compromise the validity of the study's results. Statistical manipulation is necessary to control for extraneous variables, which maintains internal validity, but often shifts the study's conclusions from authentic correlations to theoretical inferences (Frongillo, Jyoti, & Jones, 2006; Schmitt, 2010).

Thus, while a controversy persists in some quarters of the debate of food and academic performance, we tend to take the side of sound conclusions from a number of studies which demonstrate the positive correlation of healthy food intake and increased academic performance. These conclusions guide the remainder of this article.

## The Implications of Learning Theories for Food and Academics

Various learning theories contribute to one's understanding of the effect of food on the process and ability of students to learn effectively.

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*education for all: Levelling the playing field*, *CABI*; Lieberman, Kanerek & Prasad (2005). *Nutritional Neuroscience*, Boca Raton, FL: Taylor & Francis; Robertson (2009). Safety, Nutrition and Health in Early *Education*, Cengage Learning; Worobey, Tepper & Kanarek (2006). *Nutrition and behavior*: A multidisciplinary approach, Cambridge, MA: CABI Publishing.

## Maslow and One's Individual Need for Achievement

Abraham Maslow's (1943) hierarchy of needs organizes human needs from basic to sophisticated levels. In order of increasing importance, the clusters of needs included in Maslow's hierarchy are physiological needs, safety needs, belongingness and love needs, esteem needs, and the need for self-actualization. Maslow (1943) describes the body's physiological need for food, especially in terms of maintaining homeostasis of water, salt, macronutrients, vitamins, minerals, and temperature within the bloodstream. He elaborates,

> "Undoubtedly these physiological needs are the most pre-potent of all needs…If all the needs are unsatisfied, and the organism is then dominated by the physiological needs, all other needs may become simply non-existent or be pushed into the background…for consciousness is almost completely preempted by hunger. For the chronically and extremely hungry man…life itself tends to be defined in terms of eating. Anything else will be defined as unimportant" (p. 373-374).

In contrast to the directive authority of food, achievement is among the least potent of needs. According to Maslow, "all people in our society…have a need *or desire* for self-esteem …that is soundly based upon real capacity, achievement, and respect from others" (p. 381, italics added). It is important to note Maslow's postulation that once needs on one level are satisfied, needs at higher levels emerge and dominate the organism's thoughts and behaviors. Therefore, according to Maslow's hierarchy, the need or desire for achievement will not drive a person's thoughts and behaviors until needs on the lower levels have been satisfied.

As a result, the cognitive processes and behaviors associated with the more sophisticated levels on the hierarchy cannot be achieved; great academic performance cannot be expected from students experiencing basic needs deprivation. While Maslow's hierarchy offers an expository connection between food and learning, it also raises three germane questions: (1) What must be consumed to meet basic physiological needs?; (2) Do certain diets meet basic needs better than others?; and (3) Can people surpass their basic needs, thereby enabling themselves to reach superior achievement on subsequent hierarchal levels?

Maslow's hierarchy of needs provides a framework for understanding a fundamental link between food and academic performance. At a very basic level, humans who have not met their basic nutritional needs cannot attain needs at the higher levels. Vygotsky, however, adds another layer of understanding with his apt consideration of the socio-cultural dynamics germane to this topic.

## Vygotsky and One's Cultural Need for Achievement

Nutrition and academic performance are affected by an array of sociocultural factors. Distinct differences in nutrient consumption appear both internationally and among population subcultures because of food availability, preference, and social norms; these dietary trends are especially prominent in comparisons of socioeconomic status and ethnicity. Likewise, academic performance varies greatly among cultures and subcultures.

Vygotsky and the socioculturalists explain these phenomena by saying that a person's context shapes his or her behavior, such as by influencing eating habits and determining priorities in learning. They argue, "a culture defines what knowledge and skills children need to acquire" and that values and processes "differ among different races, social classes, dual-career versus one-career families, rural versus urban communities, single-parent versus two-parent families, and so on" (Vygotsky, 1978, p. 47, 50). Sociocultural factors will be more thoroughly examined through the discussion of malnutrition on academic performance.

Maslow and Vygotsky provide a context for physiological and cultural approaches for how food affects human brain function and capability as well as sociocultural attitudes toward food and academic performance.

### Other Theories

The study of nutrition requires an understanding of biological processes as well as a consideration of sociocultural factors. Theories with an established biological foundation include ethology, which studies the biological basis of development, and information-processing, which examines the network of brain activity during cognition. Historically, ethology has studied behavior from an evolutionary perspective however, contemporary ethologists focus on "the immediate causes of behavior" and most studies investigate "cells, neural impulses, and hormones" (Miller, 2011, p. 328).

Closely related, information-processing theorists generally agree "knowledge is represented by patterns of activation across units" in the brain (Miller, 2011, p. 298). The nutritional needs of the brain to carry out the neurological functions described by ethologists and information-processing theorists is a major focus of this article and will be carefully considered when nutritional neuroscience is examined.

## A Preliminary Inquiry into Factors of Food and Academic Performance

The question posed then is this: "To what extent does food impact academic performance?" To answer this question, we will summarize three topics of interest regarding the relationship between food and academic performance: nutritional neuroscience, malnutrition, and diet adequacy.

### Nutritional Neuroscience

The architecture of the brain is made up mainly of nerve cells (*neurons*) and their supporting glial cells; cognition occurs through activity within the brain's structure. A baby's brain starts to develop three weeks after conception, when neurons begin to form and to multiply (Healy, 2004). Neurons develop rapidly from the second trimester of pregnancy through the first year of life so that by age one, a baby has about 100 billion neurons and will maintain roughly the same amount through adulthood (Healy, 2004; Paus, 2010).

Though stable in number, these neurons continue to grow and to change dramatically based on the unique activities they are stimulated to undertake. In order for any human action to occur, neurons must communicate with each other. Communication between neurons (*neurotransmission*) happens when one neuron's axon sends information out if its cell and another neuron's dendrite picks up the information. The links between axons and dendrites (*synapses*), and this neural network make up the white matter (WM) of the brain (Paus, 2010).

The number of synapses varies greatly by individual and throughout development, but it is estimated that each neuron has about 2,500 synapses at birth, 15,000 synapses as toddlers, and an average of 2,000 synapses by school-age and beyond (Gopnick, et al., 1999). The number of synapses decreases as connections become more efficient and networks of connections become more permanently established. During cognition, each activated synapse fires about 200 times per second (Kagan, 2009).

Given its 100 billion neurons, each with about 2,000 synapses firing around 200 times per second, it is clear that the brain is a bustling place and that cognition is an energy-expensive activity. In fact, the brain accounts for only about 2% of a person's body weight, but consumes between 20-30% of the body's available energy and oxygen (Gustafson, 2010). This is because active neurons burn fuel to function. As they develop, children's brains are more active than adult brains: at three months, sensorimotor functions dominate infants' mental activity; when toddlers are two years old, their brain activity reaches adult levels; and children from age three through adolescence have brains that are nearly twice as active as adults' (Gopnick, et al., 1999).

All cells in the human body – including neurons and glial cells – derive energy from food calories in the form of macronutrients: carbohydrates, proteins, and fats (alcohol is also a source of energy, but is not considered a macronutrient because the body does not need it for survival). Before cells can gain energy from food, it must be converted into simple sugars, especially in the form of glucose, a simple sugar that is the primary source of fuel for the brain, nervous system, and red blood cells, and a preferred energy source for all other bodily cells and tissues (Davis & Melina, 2010; Graham, 2006). Carbohydrates provide the most efficient source of energy for the body because they easily break down into simple sugars and are quickly converted to glucose in the liver. Using either protein or fat for energy requires extra work during conversion to glucose, produces toxic by-products, and depletes the body of protein and fat needed for other bodily functions (Davis & Melina, 2010; Graham, 2006).

The World Health Organization (WHO) recommends 55-75% of humans' calories come from carbohydrate; however, the recommendation for carbohydrate intake based on the Dietary Guidelines for Americans, at 45-65%, is slightly lower. Likewise, U.S. dietary guidelines recommend a higher ratio of calories coming from fat (25-35%) and protein (10-30%) than those of the WHO (U.S. Department of Health and Human Services [USDHH] and U.S. Department of Agriculture [USDA], 2005). The minimum carbohydrate intake required for fundamental brain function is 130 grams (roughly 520 calories) per day (Davis & Melina, 2010).

Food also fortifies the body with micronutrients (vitamins and minerals) that are involved with a variety of processes that promote "neuronal survival" (Paus, 2010, p. S30). In addition, micronutrients synthesize brain chemicals called neurotransmitters that are responsible for carrying information across synapses, and support efficient transmission along these pathways (Gomes-Pinilla, 2008). Neurotransmitters "influence mood, sleep patterns, and thinking. Deficiencies or excesses of certain vitamins or minerals can damage nerves in the brain, causing changes in memory, limiting problem-solving ability, and impairing brain function" (Gustafson, 2010, p. 351).

As an energy-expensive organ, the brain requires adequate energy in the form of glucose and sufficient nutrients to function properly. The brain's energy needs are elevated throughout childhood, which suggests a more crucial need for suitable nutrition during development. The technologies that allow scientists to monitor energy metabolism in the brain provide detailed information about brain activity in various cognitive processes. In relation to academic achievement, some studies imply that students with an insufficient glucose supply or nutrient deficits will have compromised cognitive potential (Helland, Smith, Saarem, Saugstad, & Drevon, 2003; Schmitt, 2010).

## Malnutrition

**Prenatal and Early Childhood Undernutrition.** Based on the well-documented exponential growth and development of neurons and synaptic networks in children's young brains, it has been widely inferred (Allen, 1990; Dobbing, 1985; Prince & Howard, 2002) that there are critical periods in children's development when good nutrition is especially vital to healthy brain development. Other researchers (Healy, 2004), however, note the brain's ability to reroute itself and point to inconsistent results and alternative explanations to challenge studies that indicate concrete critical periods. Despite inconclusive evidence about the existence and nature of critical periods, it is accepted that sufficient pre- and post-natal calorie consumption is essential to proper brain development in infants.

Furthermore, research suggests that deficiencies in certain nutrients during children's early years impair cognitive function, including: folic acid (Gomez-Pinilla, 2008; Healy, 2004), iodine (Kretchmer, Beard, & Carlson, 1996), essential fatty acids (Gomez-Pinilla, 2008; Helland, Smith, Saarem, Saugstad, & Drevon, 2003), and iron (Allen, 1990; Kazal, 2002; Kretchmer, et al., 1996; Osendarp, Murray-Kolb, & Black, 2010). The extent of cognitive damage depends on the severity and duration of malnutrition and on the timing of malnutrition in relation to development (Gustafson, 2010).

**Later Childhood Undernutrition.** After roughly age three, when synapse development slows and synaptic pruning begins, concern about developmental malnutrition is lessened (Prince & Howard, 2002). However, voluminous research indicates that children living in poverty and underdeveloped countries remain at high risk for cognitive impairment and lower academic achievement. It is understood that children of low socioeconomic status often do not have consistent access to sufficient food; their brains, therefore, are starved, short- or long-term, for the energy and nutrients needed to function properly. Even after controlling for confounders, studies have significantly correlated food insecurity to poor mathematics and reading performance; long-term food insecurity appears to amplify academic shortfalls while becoming food secure reverses such deficits (Hollar, Messiah, Lopez-Mitnik, Hollar, Almon, & Agatston, 2010).

Conversely, food stamp participation is correlated to improvements in standardized assessment scores in reading and math (Frongillo, et al., 2005). Such studies provide compelling evidence that consistent access to and consumption of nutritious food has a significant impact on learning, and have profound implications for the nearly 11% of U.S. students who live in poverty (Armstrong, 2010). These severe repercussions are well summarized in cognitive psychologist Mark Kishiyama's statement, "The neural systems of poor children develop differently from those of middle-class children, affecting language development and 'executive function,' or the ability to plan, remember details, and pay attention" (Armstrong, 2010, p. 50).

Children in developing nations face similar challenges regarding food scarcity and consequential nutrient deficiencies. For example, Sigman, Neumann, Jansen, and Bwibo's (1989) research on malnutrition and cognition in Kenyan schoolchildren found that children with more adequate diets had significantly higher scores on cognitive skill assessments, "regardless of the social and economic resources of the family" (p. 1471-1472).

Likewise, in Malaysia, a country in Asia, the continent where more than two-thirds of the world's malnourished children reside, associations have been found between poor nutrition and low school achievement (Shariff, Bond, & Johnson, 2000), though a similar study recently found such a correlation statistically insignificant (Ong, Chandran, Lim, Chen, & Poh, 2010). Each study controlled for confounding variables and environmental factors, thereby suggesting an independent link between nutrition and academic performance.

**Childhood Overnutrition.** While caloric deficits have negative consequences on cognitive function and academic performance as described above, research indicates that an excess of calories is also correlated with effects of relevant harm. Specifically, regular caloric surpluses can "reduce synaptic plasticity and increase the vulnerability of cells to damage by causing free-radical formation" (Gomez-Pinilla, 2010). Taras and Potts-Datema (2005) reviewed nine scholarly articles to examine the possible link between obesity and school attendance, academic achievement, and cognitive ability among schoolchildren aged 5-18; each of the nine studies found significant associations between obesity and reduced attendance, poor academic achievement, or impaired cognitive skills.

Recent longitudinal research studied the effects of an obesity prevention intervention consisting of nutritional and exercise components on academic performance, and found the intervention group participants had significantly higher math scores than the control group, regardless of ethnic background and other potentially confounding variables (Hollar, et al., 2010). It is unknown whether obesity is a cause or a symptom of poor academic performance. Some research points to the social-emotional factors associated with childhood and adolescent obesity, and argue that being overweight leads to a host of mental health issues and low self-esteem, which in turns leads to increased absenteeism, and consequently to poor academic performance. The theoretical assertion that "poor school performance increases the risk of adolescents' being overweight, which, in turn, causes poor school performance" has been supported by recent research (Cho, Lambert, Kim, & Kim, 2009). Regardless of whether it is obesity or substandard academic performance that is the catalyst, there is a clear correlation between the two factors.

**Diet Quality**

In contrast to studies on malnutrition, which typically involve subjects who are severely undernourished due to long-term macronutrient deficiency, consideration of diet quality allows researchers to analyze the dietary composition of relatively well-nourished subjects. Diet quality is typically measured using the Healthy Eating Index (HEI) or the Diet Quality Index-International (DQI-I) (Fungwe, Guenther, Juan, Hiza, & Lino, 2009; Kim, Haines, Siega-Riz, & Popkin, 2003). The HEI, prominently used in the United States, measures diet quality based on the USDHH & USDA recommendations for consumption from each food group. Alternatively, the DQI-I is used internationally to measure dietary adequacy (sufficient energy and nutrients), variety (diversity among food groups), balance (macronutrient ratios), and moderation (restriction of less nutritious foods), and is thought to provide a more comprehensive analysis of dietary intake (Florence, et al., 2008).

A 2009 analysis conducted by the USDA found that American children aged 2-17 consume diets that are only about half as nutritious as recommended (Fungwe, et al., 2009). Largely, American children do not consume enough fruit, vegetables, whole grains, and legumes, and consume too much saturated fat, sodium, and extra calorie-foods (Fungwe, et al., 2009). These findings were consistent regardless of income level (Guenther, Juan, Lino, Hiza, Fungwe & Lucas, 2008). Poor diet quality has problematic consequences for students; an independent association between overall diet quality and academic performance has been demonstrated, especially in terms of diet adequacy and variety (Florence, Asbridge, & Veugelers, 2008). More specifically, increased fruit and vegetable consumption and reduced dietary fat intake have been significantly linked to improved academic performance (Florence, et al., 2008). Furthermore, a direct and significant negative correlation between fast food consumption and academic performance has been found, independent of students' weight and parental income level (Bloom, 2009).

Several efforts to improve American schoolchildren's diet quality have been initiated. Many schools serve breakfast and snacks as part of the school lunch program. Breakfast consumption is associated with improved diet quality (USDA, 1999), attendance (Huang, Lee, & Shanklin, 2006), alertness, cognitive function, and well-being (Smith, 2010); however, a clear causal link between breakfast consumption and increased academic performance has not yet been established (David, 2009-2010). The USDA's Fresh Fruit and Vegetable Program was recently expanded to include at-risk schools in all fifty states, helping to improve students' diet quality through increased fruit and vegetable consumption (Briggs, Mueller, & Fleishhacker, 2010; Jyoti, Frongillo, & Jones, 2005). Further, qualitative data reports show perceived increases in student attentiveness and decreases in hunger and obesity (Buzby, Guthrie, & Kantor, 2003). Use of multivitamin supplements to improve the quality of school-age children's diets showed no correlation to improved academic performance (Perlman, Worobey, Maillet, Tougher-Decker, Hom, & Smith, 2010). The importance of consuming a diet with ample nutrient-dense foods is suggested in these studies.

## Summary of Factors Regarding Food and Academic Performance

The human brain needs sufficient energy – specifically glucose – and a variety of micro-nutrients to perform cognitive functions. A long-term deficiency of any or numerous macro- or micro-nutrients causes malnutrition and consequential cognitive impairment, the extent of which depends on the duration and degree of the malnourishment and the timing of its occurrence in development. In the United States, macronutrient malnutrition (i.e., starvation) is rare, but the diets of America's schoolchildren lack quality as measured by adequate and varied consumption of fruits, vegetables, and whole grains, and moderation of saturated fats and extra-calorie foods. Therefore, it can be inferred that U.S. students' brains are often malnourished, as they are under-supplied of the micronutrients needed for effective cognition.

Improvements in the nutritional quality of students' diets are associated with academically beneficial gains, but have not been repeatedly and causally correlated to increased academic achievement. Concrete links between food consumption – either at large or in specific foods – and academic performance have not been established, likely because of the complex nature of the variables, the abundant confounders, and the longitudinal design necessary to understand the enduring effects. In general, however, it is clear that consistently eating sufficient quantity and variety of nutrient-dense foods will improve children's diet quality, and consequentially reduce the potential for the cognitive impairments associated with malnutrition.

## Practical Implications for Educators

A positive correlation exists between appropriate level and quality of food intake and academic performance. Educators should be aware of and instrumental, where possible, in encouraging initiatives that foster this relationship. A consideration of several practical implications are discussed below:

1. Arguably, the most pressing issue that stems from this research involves school-children's diet quality. Research about the human brain's nutritional needs, coupled with recent data that demonstrate generally poor diet quality and suggest cognitive malnutrition, compel corrective action. In the United States, where food is plentiful and government readily subsidizes children's nutritional needs, the logical course of action is to focus on improving the quality of children's diets. The School Lunch Program, along with extensions into breakfast, snacks, and summer feeding programs, makes nutritious

and varied meals accessible to children (David, 2009-2010). A more concerted effort at implementing these programs may be warranted.

2. Recent data revealing students' diets average only half of the recommended nutrients raise concern about the effectiveness of the School Lunch Program in meeting children's dietary needs for optimal cognitive function (Guenther, Juan, Lino, Hiza, Fungwe, & Lucas, 2008). Possible explanations for this incongruity include discrepancies in schools' compliance to the national dietary recommendations, variations in the school lunch items students choose to eat, and children's dietary habits outside of school. Each school district should evaluate its policies and practices regarding these programs. Nutritional education programs are often suggested, but many educational systems find it difficult to incorporate an untested program into an already rigorous curriculum with high-stakes accountability measures.
3. Changing the dietary habits of children is difficult enough, but it is virtually impossible without simultaneous parental intervention, as students' home environment determines food that is available and shapes eating patterns. Where possible, schools should not hesitate to implement nutrition reform and promote it to families and the communities because food choices are highly personal and somewhat sensitive in nature. Even with data suggesting a correlation between nutrition and academic performance, schools may justifiably feel uncomfortable and unqualified to recommend dietary changes. Additionally, opinions about "healthy" eating vary greatly among persons, families, communities, and cultures, so promoting specific food choices would likely be contentious.
4. The wide ranges of recommended macronutrient-ratio intake and food group consumption further complicate the issue. For example, some researchers (Lieberman, Spring, & Garfield, 1986) recommend high-protein intake, as they believe carbohydrate foods cause more sleepiness, and therefore academic difficulties, than do protein foods. Conversely, other researchers (Graham, 2006) promote a high-carbohydrate diet based primarily on fruit, as fruit provides a nutrient-dense form of glucose that fuels the brain with an efficient and steady source of energy and nutrients. Likely, a viable resolution lies somewhere between the two extremes; finding acceptable common ground will depend on an agency with the expertise and resources to research and publicly promote dietary changes that correlate to improved cognition. Additional research might be useful to further resolve the divided opinions about diets and food intake.
5. Food is essential to academic performance because it provides the energy necessary for cognition. Malnutrition from long-term underconsumption of macronutrients is uncommon in the United States; rather, U.S. malnutrition is typically manifested in underconsumption of nutrient-dense foods that provide the macro- and micro-nutrients to fuel optimal cognitive function. Improving children's diet quality by increasing their consumption of fruits, vegetables, and whole grains, and reducing their intake of saturated fats and extra-calorie foods will provide more adequate energy and nutrients for

the brain, though further research is needed to determine the extent of the relationship between healthy food and increased academic performance.

6. The complexities involved in studying the long-term effects of children's nutrition on their academic performance leave little established research demonstrating a causal relationship between the two; however, performance gains in related academic behaviors are better documented.
7. Additional research is needed to determine if specific foods or food groups will increase academic achievement, and if the national recommendations for nutrient consumption promote academic achievement as written. Synthesis of this type of research with information about nutritional neuroscience may provide improved nutrition education to school policymakers, information for the general public, and practices among American

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