The Assessment of Cognitive Performance in Children: Considerations for Detecting Nutritional Influences

Donna Hughes, M.Psych(Clin), and Janet Bryan, Ph.D.

The accurate assessment of cognitive performance in children is critical for detecting the effects of micronutrient deficiency or supplementation on the developing brain and its functions. Relatively little attention has been paid to the selection of culturally appropriate measures that are sensitive enough to detect the subtle cognitive changes that could be expected following nutritional intervention. Normal brain development and the emergence of cognitive abilities throughout infancy and childhood is discussed in this paper, followed by a description of the more pertinent and sensitive neuropsychological tests that can be used to assess cognitive performance and investigate the effects of micronutrient deficiency and supplementation on cognitive development among children in a variety of cultures.

Key words: nutrition, cognitive development, cognitive performance, culture fair assessment

Introduction

This review discusses the issues around the accurate assessment of cognitive performance of children, specifically in the detection of nutritional influences. There is emerging interest in the role of nutrition in cognitive performance and cognitive development of children. While there has been much emphasis on identifying key nutrients for cognition and the mechanisms by which they might affect the brain, there has been relatively little consideration of the selection of appropriate cognitive outcome measures. This review will describe the development of the brain and the emergent cognitive abilities during childhood and discuss the selection of appropriate outcome measures to assess these cognitive abilities, with an emphasis on those measures sensitive enough to detect nutritional influences. Finally, we address issues of cross-cultural assessment of cognitive performance.

Brain Development in Children

The impact of nutrition on brain and cognitive performance may depend on the timing of the nutritional impact during the child’s lifespan. An understanding of the way in which the brain develops during infancy and childhood can provide insight into the cognitive abilities that emerge during this time. The most crucial developmental period for the human central nervous system (CNS) is gestation. During this time, neurons proliferate and supporting tissues such as the circulatory system and glial cells form. Neurodevelopment during this time is rapid and any insults to the system that suppress cell proliferation in particular will not be compensated for later on. However, some developmental events, such as the myelination of neurons, continue throughout childhood. Myelination involves the development of a sheath of an insulation-type substance comprising cholesterol, fatty acids, lipids, protein, and cerebroside. This myelin sheath insulates the neuronal axons and allows minimal loss of the electrical potential, thus accelerating the speed of nerve impulses and enhancing information flow within neurons. The rate at which different brain structures myelinate ties in with the emerging abilities seen in infancy and childhood. Myelination commences slowly at approximately 16 weeks gestation in the spinal cord and cranial nerve roots. Structures that are myelinated next include the vestibulo-acoustic system, responsible for balance; the parietal cortex, which enables integration of motor responses; and the hippocampus, which is mature by approximately 12 months of age and is responsible for encoding and retrieval of memories enabling the young child to learn. Finally, the language areas in the left temporal lobe myelinate at approximately 18 months of age, enabling the acquisition and understanding of language.

Other brain structures myelinate more slowly from infancy and throughout childhood, including the struc-
tures responsible for the focus and maintenance of attention. These include the reticular formation, a group of nuclei situated at the top of the brain stem with dopaminergic and noradrenergic connections to the cerebral cortex;\(^5\) the superior colliculus; the parietal cortex; and the lateral pulvinar of the thalamus. The area that is slowest to fully myelinate is the frontal cortex, which commences myelination at approximately 6 months of age and continues throughout childhood, adolescence, and adulthood. Spurts in the development of the frontal lobes have been found to occur from birth to 2 years, 7 to 9 years, and in the mid-teens.\(^6,7\) The frontal lobes are thought to have a “supervisory” and integrative role in brain function that arises from the neuroanatomy of the brain. The frontal lobes have rich connections with all other parts of the brain with feedback and feedforward connective loops. They therefore appear to be the hub of cortical activity and the parallel nature of these connections gives the frontal lobes an influential position in the brain.\(^8\) Specifically, the frontal lobes are responsible for executive “higher-order” cognitive activities such as planning, developing strategies, and testing hypotheses when problem solving; focussing attention and inhibiting task-irrelevant information stimulation; and the higher-order aspects of memory.\(^9,10\) These abilities are therefore the latest of the cognitive abilities to emerge during childhood.

Nutrition, as part of the child’s biological environment, can have broad effects on the development of the brain’s macrostructure (e.g., the development of the frontal lobes), microstructure (e.g., the myelination of neurons), and the level and operation of neurotransmitters (e.g., dopamine levels or on receptor numbers).\(^11\) The nature and severity of the effect will depend on the timing of nutritional influences on the brain and the cognitive abilities emerging at those times.\(^12\) Specific nutrients may have specific effects on the brain and cognitive development of children, but there is much to be learned about these effects before confident predictions can be made.

In summary, different parts of the brain develop and mature at different rates. The first brain regions to mature are those involved in visual control, balance, and motor abilities, enabling exploration and interaction with the environment, and then structures such as the hippocampus, the left temporal lobes, and the right hemisphere, which enable learning, memory, language acquisition, and spatial ability. The frontal lobes, which are responsible for higher-order cognitive activity, are the last brain areas to develop. Nutritional deficiencies and other insults to the brain at various stages of gestation, infancy, and childhood are therefore likely to affect the brain functions developing at the time.

---

**Development and Assessment of Cognitive Abilities**

The development of different parts of the brain underlies the development of associated cognitive abilities, which are the observable outcomes of brain function. The effects of nutrition on the development of cognitive abilities are likely to be subtle because nutrition is only one of many influences on brain and cognitive development. The choice of cognitive outcome measures is therefore an important consideration in the detection of nutritional effects. Cognitive outcome measures should have good psychometric properties and, wherever possible, be standardized for administration in the country or culture in which they are to be used. They should be sensitive to subtle nutritional effects as demonstrated by variability in performance without displaying floor (i.e., the test is too difficult for most children) or ceiling effects (i.e., the test is too easy for most children), and they should be able to detect changes in performance over time. Each test should be selected according to the effects that are expected to arise owing to the nutritional impact and should be a relatively “pure” measure of the specific cognitive ability being tested. Table 1 provides a selection of tests that fit these requirements for the assessment of cognitive development and performance in school-aged children.\(^13-36\) The tests are listed according to the specific cognitive abilities they assess. Each test has been found to be sensitive to changes in brain function arising from nutritional influences or neurologic conditions. In addition, each test has recent norms and requires minimal adaptation for use in different cultures. These tests are widely used in research and in clinical settings and are attractive to children.

The assessment of specific cognitive abilities provides an understanding of the impact of nutritional effects on different parts of the brain at different stages of brain development. Two such cognitive abilities, attention and speed of information processing, are thought to develop first and be fundamental to the development and expression of other cognitive abilities such as learning, memory, and the executive functions. The combination of these abilities helps to comprise the construct of intelligence and give rise to functional outcomes such as school performance. A model of the development and structure of these cognitive abilities is presented in Figure 1. The development of these cognitive abilities during infancy and childhood can be influenced by nutrition as well as factors such as physical development, social, cultural, and environmental interactions.\(^9,37\) Following the structure outlined in Table 1, the nature and development of each of these specific cognitive abilities will now be described, along with a description of the tests listed in the Table that can be used to assess each ability. Information regarding previous use of these tests
<table>
<thead>
<tr>
<th>Cognitive Abilities and Tests</th>
<th>Norm Details</th>
<th>Prior Use in Nutritional Studies</th>
<th>Suitability for Use across Cultures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Attention</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual Attention</td>
<td>USA(^{13}) 3–12 years</td>
<td>Similar task used to assess effects of zinc + micronutrients(^{26})</td>
<td>With minimal adaptation</td>
</tr>
<tr>
<td></td>
<td>Finland(^{14}) 3–12 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sweden(^{15}) 4–7 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creature Counting</td>
<td>Australia(^{16}) 6–16 years</td>
<td>None, but test sensitive to effects of ADHD and traumatic brain injury(^{16})</td>
<td>Very minimal adaptation, if any</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digit Span Forwards</td>
<td>As for WISC-III</td>
<td>Iodine(^{18,27,28})</td>
<td>Translation of digits required</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Speed of Information Processing</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symbol Search</td>
<td>As for WISC-III</td>
<td>None, a modified test (visual search) has been used to assess effects of iodine(^{27,28})</td>
<td>Minimal modification, if any</td>
</tr>
<tr>
<td>Coding</td>
<td>As for WISC-III</td>
<td>Iron(^{31}) Vitamin B(<em>{12}) (^{30}) Folate, vitamin B(</em>{12}), vitamin B(_{6}) (^{32})</td>
<td>Minimal modification, if any</td>
</tr>
<tr>
<td><strong>Learning and Memory</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digit Span Backwards</td>
<td>As for WISC-III</td>
<td>Vitamin B(_{12}) (^{30})</td>
<td>Translation of digits, but repeating in reverse order may not be a familiar concept in some cultures</td>
</tr>
<tr>
<td>RAVLT</td>
<td>Australia(^{18}) 7–15 years</td>
<td>Folate, vitamin B(<em>{12}), vitamin B(</em>{6}) (in adults)(^{32})</td>
<td>Translation and some modification of choice of words required</td>
</tr>
<tr>
<td></td>
<td>Australia(^{19}) 7–14 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>France(^{20}) 5–16 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Metanorms(^{21}) All ages</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Executive Functions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Block Design</td>
<td>As for WISC-III</td>
<td>Iodine(^{33}) Vitamin B(_{12}) (^{30})</td>
<td>Minimal modifications, if any</td>
</tr>
<tr>
<td>Verbal or Design Fluency</td>
<td>As for visual attention</td>
<td>Iodine(^{27,33})</td>
<td>Design fluency more suitable across cultures</td>
</tr>
<tr>
<td>Stroop Test</td>
<td>Canada(^{22}) 7–12 years</td>
<td>Black-and-White Stroop only: Iodine(^{27,28}) Vitamin A and iron(^{34})</td>
<td>Color names may be difficult to translate; cross-cultural versions developed</td>
</tr>
<tr>
<td><strong>Intelligence</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WISC-III</td>
<td>USA(^{23}) 6–16 years</td>
<td>Iron(^{35,36})</td>
<td>Nonverbal subtests require minimal modification, verbal subtests may not be suitable</td>
</tr>
<tr>
<td></td>
<td>Canada(^{24}) 6–16 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>France(^{25}) 6–16 years</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ADHD = attention deficit hyperactivity disorder, WISC-III = Wechsler Intelligence Scale for Children, PUFAs = polyunsaturated fatty acids.
in nutritional or cross-cultural research is also provided.\textsuperscript{26–36,38}

**Attention**

The ability to focus and sustain attention, to divide attention between stimuli, and to inhibit distraction is essential for learning.\textsuperscript{9} Because the brain regions responsible for attention abilities mature at different rates, the development of these abilities continues through childhood. For example, the focusing of attention has been found to reach adult levels during mid-childhood, whereas the ability to sustain attention and inhibit distraction continues to improve into adolescence and early adulthood with the maturation of the frontal lobes.\textsuperscript{9}

**Assessment of Attention**

Tests of attention can tap the different aspects of attention, including focus, sustained focus (vigilance), divided attention, and inhibition of distraction.\textsuperscript{9} Attention can also be assessed in different modalities such as visual, auditory, and motor modalities. Examples of different tests of attention include Visual Attention from the Developmental Neuropsychological Assessment (NEPSY),\textsuperscript{13} Creature Counting from the Test of Everyday Attention for Children (TEA-ch),\textsuperscript{16} and Digit Span Forwards from the Wechsler Intelligence Scale for Children, third edition (WISC-III).\textsuperscript{23}

Visual attention assesses visual focusing and the ability to inhibit distracters. The test requires the child to find and mark all occurrences of a target stimulus (e.g., a cat or child’s face) amongst distracter items. Visual Attention performance has been found to be compromised in children with traumatic brain injuries.\textsuperscript{13} A similar test was used by Sandstead et al.\textsuperscript{26} in a zinc intervention study of 6- to 9-year-old Chinese children. Those children receiving either zinc or a combination of zinc and micronutrients demonstrated improved test performance compared with children receiving a micronutrient supplement alone.

Creature Counting assesses the ability to switch attention and inhibit distraction. The test requires children to repeatedly switch between counting up and counting down as they count pictures of alien creatures on a page. Performance on this test was found to be less accurate in children with attention deficit hyperactivity disorder or traumatic brain injuries.\textsuperscript{16}

Digit Span Forwards assesses children’s auditory attention span and the ability to focus on auditory information. Digit Span Forwards requires the child to repeat a series of non-sequential digits in series ranging from two to nine digits that are spoken aloud by the examiner. This test has been used in several studies that compared children with nutritional deficiencies with matched controls. Performance on the test was poorer among children who were iodine deficient and goitrous, indicating a dysfunctional thyroid,\textsuperscript{38} in boys (but not girls) with dyslexia who were more deficient in PUFAs,\textsuperscript{29} and in adolescents with higher serum methylmalonic acid ratings (MMA, a biomarker for early vitamin B\textsubscript{12} deficiency).\textsuperscript{30} By contrast, in an iodine intervention study in Bangladesh, no difference in performance was found between the group of children taking iodized poppy seed oil supplements and children taking a placebo for 4 months.\textsuperscript{27}

**Speed of Information Processing**

The rapid processing of information is another cognitive ability that is believed to influence how well the infant and child is able to learn from the environment. Speed of information processing is thought to rely on the integrity of neural communication within the CNS. Age-related changes in speed of processing are seen throughout childhood; the time taken to process information decreases as age increases. Typically, the processing speeds of children aged 8 to 10 years old are five to six standard deviations slower than those of young adults, and 12- to 13-year-old adolescents have processing speeds one standard deviation below those of young adults.\textsuperscript{39} These developmental improvements in processing speed are consistent with age-related increases in neural myelination and in the numbers of neural connections forming throughout the CNS.\textsuperscript{40} Kail\textsuperscript{40} suggests that developmental increases in processing speed are responsible, either directly or indirectly, for age-related development in other cognitive abilities. For example, increases in speed of processing could directly facilitate improvements in memory by increasing the speed of retrieval from long-term memory, or by improving problem-solving abilities indirectly by the more rapid transfer of information in and out of working memory.

**Assessing Speed of Information Processing**

Speed of information processing is the speed at which various cognitive activities are performed in different modalities (e.g., visual, auditory). Widely used tests of speed of processing include Symbol Search and Coding, both of which are subtests from the WISC-III\textsuperscript{23} and both of which assess visuo-spatial (or perceptual) speed of
information processing. Symbol Search requires children to quickly search for and decide whether a target symbol appears among distracters. Coding requires children to quickly pair either shapes or numbers with a symbol. In both tasks, children are required to work as quickly and as accurately as possible. To date, tests of speed of information processing, including Symbol Search and Coding (or tests of similar design), have not been found to be associated with deficiency or supplementation of iodine, iron, or B vitamins.

**Learning and Memory**

Attention and speed of information processing are hypothesized to underlie the cognitive abilities of learning and memory. Learning and memory are thought to involve a system of structures or a series of processes. The structures of memory include short-term memory, working memory, and long-term memory. Short-term memory temporarily holds incoming sensory information for a limited period, from approximately 30 seconds to several hours if a rehearsal strategy is utilized. Working memory stores active, on-line information, has a limited capacity, and is thought to be critical for all cognitive processes because it simultaneously stores and manipulates limited amounts of information during the performance of various cognitive activities. Working memory functions are thought to be related to the frontal lobes. Long-term memory stores memories for facts (semantic memory), experiences (episodic memory), and sequences of motor skills for longer periods.

The processes of memory include encoding, storage, and retrieval. Encoding refers to the laying down of the memory trace and underlies the process of learning. Storage refers to the process of filing information away for later use, and retrieval to the process of searching for and retrieving information, usually by the use of externally or internally generated cues. The temporal lobes are involved in more automatic retrieval of information, and the frontal lobes are responsible for strategic retrieval search. The processes of memory are thought to transfer information from one memory store to another. For example, encoding transfers information from short-term storage to long-term storage via working memory, and retrieval brings information from long-term storage into working memory.

The development of attention and processing speed, which subserve memory functions, may account for the age-related improvements in memory abilities noted throughout childhood, especially between ages 6 and 11. Some hypotheses suggest that the development of memory is due to age-related increases in information processing speed, which may be due to increases in the number and complexity of neural connections throughout the brain. Other hypotheses link memory development to improvements in the ability to focus attention and inhibit distraction, to enabling better concentration and effort, or to improvements in the ability to use memory strategies, thus implying links with frontal lobe maturation. Investigators have suggested that it is the use of memory strategies, rather than memory storage capacity (which is believed to be similar in children and adults), that develops with increasing age. If this is true, improvements in memory may in fact occur simultaneously with the development of the executive functions. These different hypotheses are underpinned by the implication that memory improvement is dependent upon and concurrent with improvements in other cognitive abilities, stemming from underlying brain development and interconnections. This, along with the knowledge that memory abilities draw upon the functioning of many different brain regions, suggests that memory is particularly vulnerable to insult to the brain at any stage in the lifespan, but particularly during childhood.

**Assessment of Learning and Memory**

Different methods of measurement of memory performance can tap the different processes and structures. Free recall tasks in which individuals learn information without aid tap the processes of encoding and retrieval. If the information is required to be remembered immediately after presentation, information that has been stored in short-term or working memory is elicited and delayed recall of information taps that stored in long-term memory. Cued recall or recognition tasks provide a reminder to aid in the retrieval of information, and these tasks tap the encoding process, as support for retrieval is supplied by the task requirements. Incidental recall tasks require recall of information that individuals did not know they would be required to remember, and therefore rely mainly on retrieval processes.

There are many tests that are ideal for the assessment of learning and memory: this paper will discuss two that are widely used: Digit Span Backwards from the WISC-III and the Rey Auditory Verbal Learning Test (RAVLT). The List Learning subtest of the NEPSY is very similar to the RAVLT. Digit Span Backwards assesses working memory for auditory information. The test requires the child to repeat back a series of non-sequential digits in the reverse order following verbal presentation by the examiner. The digit series range in span from two to eight digits, with two trials for each series span. This test has not been widely used in nutrition research; however, in a study of adolescents who had consumed either a macrobiotic or omnivorous diet since birth, Louwman et al. found a significant negative association ($\beta = -0.24$) between vitamin $B_{12}$ status and performance on the test.

The RAVLT assesses a variety of aspects of memory performance, including immediate and delayed recall.
and recognition. In addition, learning of words over five trials can be assessed, which makes the RAVLT useful in assessing various structures and processes of memory performance. The test requires children to remember 15 unrelated words over five presentations, again following an interference list, and then to recognize them from a list containing the original words plus 15 distracter items. Children with attention deficit disorder, autism, or fetal alcohol syndrome performed less well than same-age non-affected peers on the NEPSY’s List Learning test. In addition, recall and recognition performance on the RAVLT was found to improve in adults after supplementatin with folate, vitamin B₁₂, or vitamin B₆ for 5 weeks.

Executive Functions

The executive functions refer to a cluster of abilities that include dealing with novelty, planning and implementing strategies for performance, monitoring performance, using feedback to adjust to future responding, vigilance, and inhibiting task-irrelevant information. These activities are thought to be superordinate or “meta” cognitive activities, overarching all other cognitive activities (such as attention, speed of processing, memory) and controlling and integrating their actions. They are specifically engaged when an individual is required to respond consciously and strategically to novel situations or stimuli, rather than in situations that require routine, well-learned behaviors. The executive functions are thought to develop relatively late in childhood and draw upon cognitive processes that emerge from many parts of the brain; therefore, age-related development in executive functions are likely to be associated with the development of other cognitive skills such as attention, speed of processing, language, and memory. Not surprisingly, executive functions are found to be compromised following damage to many parts of the brain, as well as to the frontal lobes. Very little research has been done to investigate the impact of nutritional deficiencies on executive functions in children, but it is hypothesized that these functions would be particularly vulnerable given their developmental timeframe.

Assessing Executive Functions

Because the executive functions are a cluster of complex abilities that draw upon many different specific cognitive abilities, it is difficult to identify one, or a few, “pure” tests, and the tests that have been deemed “executive” have difficulties with poor reliability. Three widely used tests that measure different aspects of executive function have been selected for review here: Block Design from the WISC-III as a measure of problem solving, tests of fluency as measures of strategic retrieval search, and the Stroop test as a measure of vigilance and the ability to inhibit task-irrelevant information. These tests were selected from those recommended by a number of authors based on their wide usage, validity, and potential to detect executive dysfunction arising from age, development, or neurologic conditions. Other tests such as maze tasks (e.g., Porteus) and the Tower Test and Knock and Tap from the NEPSY are also worthy of investigation in nutritional studies.

Block Design assesses visuo-spatial organization, problem solving, non-verbal abstract reasoning, and concept formation. The task requires the child to reproduce twelve designs of increasing difficulty as quickly as possible by using red and white blocks. Performance on this test has been found to be sensitive to vitamin B₁₂ deficiency in adolescents and to changes in iodine status following 12 months’ supplementation. Tests of fluency include tests of verbal fluency, in which children are required to generate as many words as possible either beginning with a designated letter or from within a semantic category, and design fluency in which children are required to generate as many novel designs as possible. Fluency tasks measure the speed and ease with which people can access words from memory or generate ideas. Performance on verbal fluency tests has been found to be poorer in children suffering from some neurologic or acquired CNS disabilities, in children who are hypothyroid, and children who have low vitamin B₁₂ levels than in matched controls. The Stroop test comes in many forms, the original being the “Color-Word” Stroop, and others including the “Black-White” Stroop, and the “Sun-Moon” and “Fruit” Stroop, which were designed for children from different cultural backgrounds. Each version requires the child to ignore a habitual response (such as reading the name of a color) in order to perform a non-habitual response (such as naming a color that is incongruent with a color name). Therefore these tasks measure the ability to inhibit task-irrelevant information, mental flexibility, and self-monitoring. Performance on the Black-White Stroop was found to improve in a sample of rural African children following supplementation with iron, vitamin A, or a combination of the two; however, no improvement was observed following iodine supplementation for 4 months in an Indian trial.

Intelligence

Intelligence is term that describes an individual’s general cognitive ability across a range of different aspects such as the abilities described above. Most tests of intelligence concentrate on the assessment of problem solving, verbal ability, and acquired knowledge. Problem solving and verbal ability are commonly referred to as “fluid” and “crystallized” intelligence, respectively. Fluid intelli-
Assessing Intelligence

Intelligence is typically measured using a battery of tests, which when combined give a measure of global ability (e.g., Intelligence Quotient [IQ]). Current intelligence test batteries for school-aged children include the WISC–III, the Kaufman Assessment Battery for Children, and the Stanford-Binet Intelligence Scale, fourth edition. Intelligence of pre-school children may also be assessed by a test battery specifically aimed at younger children such as the Wechsler Preschool and Primary Scale of Intelligence, Revised, and general cognitive ability of infants and toddlers is commonly assessed using the Bayley Scales of Infant Development. The Bayley Scales do not adequately assess intelligence, but rather the test taps patterns of behavior across domains, one of which is thought to be an estimate of early mental development. The Bayley scales do not have good test-retest reliability and are poor predictors of later intelligence and cognitive performance. Therefore, the accurate estimation of IQ may not be possible until the child reaches approximately the age of 5.

The WISC-III is one of the most widely used tests of the intelligence of children. It consists of 13 subtests that assess verbal and nonverbal skills with five core verbal subtests making up the Verbal Scale, and five core nonverbal subtests making up the Performance Scale. Several of these subtests are reviewed separately in this review. Scores on subtests are summed to produce Verbal and Performance intelligence quotients (VIQ and PIQ: mean = 100, SD = 15), which are combined to form an estimate of Full-Scale IQ (FSIQ: mean = 100, SD = 15). Full batteries are time-consuming to administer, but IQ can be estimated by using short forms including a few subtests. Recommendations for a number of reliable and valid short-form dyads (two-test batteries), triads (three-test batteries), tetrads (four-test batteries), and pentads (five-test batteries) are provided by Sattler.

Assessing Academic Achievement

Academic achievement can be assessed using school grades and teacher ratings of school performance. In addition, there are a number of instruments that assess specific learning outcomes such as reading, spelling, and arithmetic. Academic achievement have been found to be protein-energy malnutrition; deficiencies in iron, iodine, and vitamin A; viral or parasitic infections; hunger; and missing breakfast, especially in children who are undernourished.

Selection of Tests to Detect Nutritional Influences

Table 1 contains a list of recommended tests to assess different cognitive abilities in children. The tests are all attractive and engaging to children, and a combination of...
these tests can be collated to form a battery for an assessment session, keeping in mind that batteries of tests should take no longer than one hour to complete for children aged 5 to 12 years.

As shown in Table 1, most of the tests reviewed here have been used in studies assessing the effects of nutrition on cognitive abilities. The tests of attention have been found to be sensitive to zinc supplementation,26 iodine,38 PUFAs,29 and vitamin B1230 deficiencies. There is some evidence that the tests of memory may be sensitive to vitamin B12 deficiency30 and to supplementation with folate, vitamin B12, and vitamin B6 in Australian women.32 The construct of executive function has not been specifically investigated as a cognitive outcome of nutritional deficiency or intervention. However, there is some evidence that Block Design may be sensitive to vitamin B12 deficiency30 and to supplementation with folate, vitamin B12, and iodine deficiency27,33 and iodine supplementation.33 Performance on the Black-and-White Stroop test improved after iron, vitamin A, or a combination of both supplementation.34 This test, along with a test of semantic fluency, showed no effect of iodine deficiency.27,28 By contrast, tests of speed of information processing have not been found to be sensitive to iodine27,28 or B1230 deficiencies. Interventions with folate, vitamin B12, vitamin B6,37 and iron31 have not affected the performance of these tests of speed of processing. The results are surprising as speed of processing is a cognitive ability that is expected to develop during childhood and the tests reviewed here have been found to be sensitive to other impacts on the CNS.

Cross-cultural Assessment of Cognitive Abilities

Cognitive tests are devised within a particular culture and therefore contain stimuli that relate to that culture’s social customs, images, and vocabulary. Indeed, most cognitive tests are developed in the United States and Europe, and children from other cultures may not find the stimuli familiar or acceptable. These children may also differ in their understanding and acceptance of the testing process, such as working one-to-one with the examiner, being asked questions directly, being required to provide lengthy verbal responses, or being asked to work within strict time constraints.66,67 For example, when testing a sample of Jamaican children, Baddeley et al.67 noted that while it was difficult for the children to negate incorrect statements made to them by an adult examiner, they could comfortably respond if the statements were rephrased as questions.

Selecting tests that have been developed within the culture of interest will overcome many difficulties; however, where local tests and norms are unavailable, adaptation of tests used in other cultural settings may be necessary. Verbal modifications include the translation of instructions and content to the local language while maintaining the verbal demands of the test. Simple translation is not enough when the test demands different things of the two languages. Reading a list of words in an irregular language such as English is a challenging task for children; however, reading the translated list of words in a language such as Bahasa Indonesia will not be as demanding because the language is phonetic and rule oriented. Simple translation is also not sufficient when item content is unfamiliar to one culture; for example, simple translation would not be appropriate if translating from a language in which different words are used to describe several related items (e.g., boat, yacht, ship) into a language in which only one word is commonly used to describe all of the items (e.g., boat). For tests using pictorial stimuli, changing images and symbols to those more familiar or changing the ethnic appearance of images of people are necessary modifications. Many of the tests listed in Table 1 require minimal modification for use cross-culturally.

Conclusion

The brain develops throughout infancy and childhood and gives rise to cognitive abilities that are multidimensional and hierarchical. Abilities such as attention capacity and speed of processing appear to underlie other abilities such as learning, memory, and executive function. Many of these abilities form what is known as intelligence and can be manifest in readily observable outcomes such as academic achievement. There are many tests that adequately assess these abilities and of these; the tests reviewed in this paper are pertinent tests of the cognitive abilities that develop during childhood, show variability in performance without ceiling or floor effects in normal populations, could withstand repeated administrations over time, may be sensitive to detect nutritional effects, require few if any cross-cultural modifications, and are attractive to children.

Acknowledgement

This review was funded by the Unilever Health Institute, The Netherlands.