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Neuropsychological Considerations

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Effective treatment planning rests upon appropriate assessment and diagnosis. The purpose of this chapter will be to present an overview of how neuropsychological assessment is the foundation for behavioral treatment of the brain-injured child. The specific assessment procedures covered include interview assessment and major neuropsychological test procedures for children, specifically the age-appropriate extensions of the Halstead-Reitan Neuropsychological Battery, the Luria-Nebraska Neuropsychological Battery-Children's Revision (LNNB-CR), and Kaufman Assessment Battery for Children (K-ABC). However, before these specific procedures are addressed, an understanding of central nervous system anatomy and function is essential to the useful application of current neuropsychological evaluation procedures.

Developmental Neuroanatomy and Function

The section presents an elementary description of developmental brain-behavior relationships. Such an understanding is critical to the development of appropriate evaluation methodologies. In turn, the efficacy of these methodologies will directly affect the application of subsequent behavioral treatment planning. Special attention will be given to: (1) Luria's model of brain function, (2) hemispheric lateralization of function, and (3) recovery of function after childhood cerebral trauma.

Luria's Model of Brain Functioning

There are important differences between child and adult cerebral organization and localization of function. A child's brain, in terms of localization of functions, is both less well studied and more inherently difficult to understand than an adult's brain. There is a greater degree of variation in the expression of human abilities subserved by a child's cerebral hemispheres. Children are in the process of development and are prone to various poorly understood growth spurts, developmental stages, and developmental lags. Since children are in the process of acquiring their academic and daily living skills, it is difficult to accurately determine age appropriate neuropsychological behavior. By contrast, adult brains are easier to understand, since their neuropsychological abilities are relatively stable. Also, the neuropsychology of adults has been the subject of disciplined inquiry for several decades. By contrast, with the neuropsychology of children there is considerably less data. One model particularly well suited to understanding brain-behavior relationship in children has been postulated by Alexander Luria.

Three Major Brain Blocks

Luria (1966) proposed a conceptual model for the organization of higher mental processes and the behavioral correlates of specific brain areas. Grossly over-simplified, Luria (1966) postulated three major brain areas or systems. These included the brainstem structures, the cerebral cortex posterior to the central sulcus, and the cerebral cortex anterior to the central sulcus. Each major system makes a specific contribution to human cognition. The brainstem structures are responsible for the tone and energy level of the cerebral cortex. Much like the electrical supply to a personal computer must be stable and constant for the arithmetic/logic unit to work, so do the brainstem structures support the mental activity of the cerebral cortex.

The second major area functions in a different way. The posterior cerebral cortex deals with the perception of the senses, by receiving, organizing, and retaining visual, auditory, and tactual stimuli. The third major system completes the conceptual model. The anterior cerebral cortex is responsible for emitting motor responses and the formulation of intentions, plans of behavior, and their evaluation. Luria (1966) further postulated that the second and third systems of the cerebral cortex are divided into primary, secondary, and tertiary areas. The second block (i.e., posterior cerebral cortex) will be used as an example to illustrate the concept. Essentially, the primary areas perform very basic functions of sensory input of either visual, auditory, or tactual stimuli. For example, the primary area would tell whether or not a child was touched, but a

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secondary area could tell if the stimulus was an X or O drawn on the skin. Tertiary areas would combine two or more secondary areas to subserve complex mental activities such as handwriting. Alternatively, information from different senses is combined to perform higher level human behaviors.

Functional Systems

Luria (1980) proposed that different areas of the brain are combined into functional systems. Specific sections of the brain in each of the three blocks combine to produce behavioral performance. Functional systems could also be created by using different routes in the brain but could yield the same ultimate behavioral outcome. A simple example would be that reading can be taught by either linguistic analysis or sight reading (Horton & Wedding, 1984). Abilities postulated to reside in the temporal lobe are important; other crucial skills are performed by abilities postulated to reside in the occipital lobe. As stated, the actual behavioral performance is the same, but the combination of brain areas responsible for production may vary markedly.

Neuropsychological Developmental Stages

In addition to postulating the different roles played by separate brain areas, Luria (1980) also suggested that the higher cortical functions were developed in conjunction with environmental stimuli in different stages. To a degree, this refers to Luria's work on Volgotsky's Cultural Historical Theory (Horton, in press). Highly complex functional systems are not available in a toddler. Luria (1980) averred that cultural, historical, and social influences upon a child, as he or she matures, are important in shaping the contributions of available brain areas. Thus, the development of higher cortical functions, such as language, intentional memory, and abstract thought are the product of both the development of neuroanatomical structures and the cultural, historical, and social environmental stimuli experienced by the child.

Luria (1980) proposes the notion of five stages for the development of higher cortical functions and intentional mental activity. These ideas are based on his conceptualization of the three basic blocks of the brain. The first stage, beginning in the first year of life, is devoted to the development of the reticular activating system. These subcortical structures are contained in the first block. The second stage overlaps with the first stage to a significant degree. Here the primary sensory areas of vision, hearing, and tactual perception and the primary motor areas of gross motor movement come into play. For the most part, this stage is programmed by neurological structures (i.e., hardware) rather than environmental influence (i.e., software) (Luria, 1980). As later stages emerge, these areas become integrated into more complex neuropsychological patterns. The third stage focuses on the single modality secondary association areas of the brain. This stage moves the toddler to the preschool realm. The child is able to recognize and reproduce words, shapes, and movement. Generally, modalities of learning are accessed, separately.

At this stage, of course, cultural-historical-social influences are crucial in shaping the child's development, as the task of assuming the culture's collected wisdom (i.e., reading, writing, arithmetic) begins. The fifth stage of Luria's (1980) conceptualization of neuropsychological development concerns the prefrontal lobes of the cerebral cortex. While the fourth stage in Luria's (1980) paradigm is activated at about the time a child begins elementary school, the fifth stage only becomes activated during adolescence or later. The prefrontal lobes, of course, are crucial for the development of abilities for the planning, executional, and evaluation of complex human behavior, critical judgment, and concept formation.

Luria's (1980) conceptualization of neuropsychological development suggests two significant points. First, it implies that there are qualitative differences between children at different stages of neuropsychological development. Thus, children will utilize different neurological structures to perform different behaviors or tasks at different ages. There is an interaction between the child's stage of neuropsychological development and the sort of behavioral tasks the child can perform competently. Second, Luria's (1980) conceptualization of neuropsychological stages suggests that children could use different functional systems to perform the same task. While the final behavioral performance could be the same, the combination of brain areas utilized could vary. This concept has important implications for the retraining of brain-damaged children. It provides a rationale for a remediation approach that concentrates on developing functional competence by reorganizing the neural pathways that combine to produce the final behavior regarding the neuroanatomical localization of a higher level of behavior with respect to Luria's theory.

Hemispheric Lateralization of Function

Cerebral asymmetry refers to morphological differences between the two cerebral hemispheres. The two cerebral hemispheres are not identical. While they are very similar, in most right-handed individuals, the left cerebral hemisphere is slightly larger than the right cerebral hemisphere (Connolly, 1950). The usual explanation for this size disparity is the special role that the left cerebral hemisphere plays in language (Geschwind & Levitsky, 1968). It is assumed by many that those areas which deal with spoken language and written symbols for communication have become enlarged, as oral communication and reading and writing have become more important to the survival of the human race. Of particular interest to the clinical child neuropsychologist are reports that autopsy examinations of children with documented reading problems reveal that the right cerebral hemisphere is larger than usually found (Rosen, Sherman, & Galaburda, 1986). These data have been interpreted by some workers in the area of child neuropsychology as suggesting a neuroanatomical basis for dyslexia.

Contralateral control is the term used to refer to the organization of the human nervous system at the level of the cerebral hemispheres. The cerebral hemisphere on one side controls the sensory-motor functions of the opposite side of the body. Thus, the right cerebral hemisphere controls visual, auditory, tactile sensations, and gross motor functions on the left side of the body and vice versa. All of these sensory abilities are not 100% under contralateral control, while vision is completely under contralateral control (at least visual function at the level of the cerebral hemisphere), auditory perception is 80%/20% under contralateral/ipsalateral control, and tactile perception is 90%/10% under contralateral/ipsalateral control.

Hemispheric Abilities

The cerebral hemispheres are specialized in terms of the behavioral functions to which they make contributions. While some clinical understanding of these unique abilities of the cerebral hemisphere were identified in the 1870s by the famous English neurologist Hughlings Jackson, they were generally accepted by neuroscientists only after the findings of the split-brain research of Roger Sperry (1961) was widely circulated. Sperry conducted a series of experiments with patients who had the connections between the two cerebral hemispheres surgically removed. One method of treatment for severe intractable epilepsy is to surgically cut the fibers connecting the two cerebral hemispheres. This usually means the corpus callosum, the main set interhemispheric fibers, but can include cutting the anterior commissure and hippocampal commission (two sets of secondary interhemispheric fibers). As a result of this neurosurgical procedure, the patients are less troubled by seizures. A secondary effect, however, is that the two cerebral hemispheres are disconnected and function somewhat independently (Golden, 1978; Horton & Wedding, 1984).

As observed by Nebes (1974):

> In contrast to earlier studies of patients with unilateral brain damage where there are great difficulties in controlling for multiple confounding variables, in the commissiurotomy patients the two cerebral hemispheres are relatively intact and available for separate testing, allowing comparison with a single person of the two sides of the brain on a given task. (p. 1)

While there is some agreement that each of the two cerebral hemispheres mediate different behavioral functions, there is less agreement regarding the actual developmental stage where various behavioral functions are subserved by various brain structures (Dean, 1985). Some researchers propose that young children do not have behavioral functions subserved by the frontal lobes while others dispute this.

The left cerebral hemisphere is usually thought of as specialized for language and speech. The abilities subserved include understanding and producing speech, reading, writing, arithmetic, and other use of symbols for communication purposes.

The right cerebral hemisphere is usually thought of as specialized for visual-spatial and perceptual motor skills. These abilities include orientation in space, drawing geometric patterns, facila recognition, and discrimination of nonverbal material (Golden, 1978). Also, processing of emotional data is subserved by the right hemisphere (Saxby & Bryden, 1984).

Bryden and Saxby (1985) postulate that the hemispheric lateralization of functions begins early in life. By age three, over 90% of all children demonstrate superior left hemispheric language processing abilities. After age three, research has failed to find major development differences between the left hemisphere's better abilities with language or the right hemisphere's superior skill in reading body language (Bryden & Saxby, 1985; Saxby & Bryden, 1984, 1985). The development of lateralized preference for handedness and footedness follows a similar age-related pattern. Preference for the right hand in the majority of children appears by age two (Bryden & Saxby, 1985), while preference for the right foot is developed in most cases by age five (Porac & Coren, 1981). There are some indications that abnormal hemispheric lateralization could be related to reading difficulties (Corballis, 1982, 1983).

Specific Functions of Cerebral Lobes

There is a considerable body of clinical and research literature regarding the behavioral correlates of lesions in specific cerebral lobes. Again, most of this literature has been developed from the adult population. While a lesion in any area may be correlated with a behavioral deficit, this does not suggest the lesion to be causally related to the behavioral. To the contrary, it is likely that the actual relationship is quite subtle and complex.

Frontal Lobes. The frontal lobes are responsible for the planning, execution, and evaluation of motor behavior. Many of the abilities subserved by the frontal lobes include goal-directed behavior, time-span judgment, and intentional memory (Struss & Benson, 1984). Some affective changes are associated with frontal lobe impairments.

The left frontal lobe is particularly involved in the production of speech. It includes Broca's area, which is intimately connected with motor speech. Unique behavioral deficits include impaired word fluency, inability to regulate external behavior by complex internal speech rules, and difficulties with verbal memory.

The right frontal lobe is particularly involved with the ability to sing. Problems in motor visual-spatial integration (Teuber, 1963) and maze learning (Corkin, 1965) are also common with lesions in this area.

Temporal Lobes. The temporal lobes are concerned with the perception, analysis, and evaluation of auditory stimuli (Luria, 1966). The temporal lobes are also important participants in the neuropsychological structures subserving memory functions. The actual entry of the verbal or nonverbal material into long-term memory, however, depends on the action of the hippocampus and other structures of the limbic system (Nauta, 1964).

The left temporal lobe is involved in the auditory perception of verbal stimuli, such as sounds of letters, words, and numbers. Impairment of the left temporal lobe can result in difficulties in the analysis and integration of auditory language (Luria, 1966). Resulting problems in phonic analysis can impair reading, writing, and spelling skills, as the decoding of language phonemes is an integral part of these processes (Golden, 1978). The left temporal lobe is also involved in verbal short-term memory (Milner, 1958).

The right temporal lobe is involved in the auditory perception of nonverbal stimuli such as rhythm and pitch. Impairment of the right temporal lobe can render a person unable to comprehend music. Nonverbal memory is also associated with the right temporal lobe (Meier & French, 1965).

Parietal Lobes. The parietal lobes mediate tactile and kinesthetic perception. Lesions in the parietal lobes produce problems in accurately appreciating tactile stimuli, including an inability to recognize objects by tactile sensitivity and an inability to integrate tactile information and kinesthetic input (Golden, 1978). Another area of deficit is an inability to consider multiple aspects of an object at the same time (Luria, 1966). Several difficulties with skilled voluntary motor movements are thought to be attributed to parietal lobe impairment (Horton & Wedding, 1984).

The left parietal lobe is of great importance in verbal information processing due to its central position between the temporal and occipital lobes. The tri-lobe (i.e., temporal, pariental, occipital) region, is responsible for facilitating language communication and it coordinates and integrates information from visual, auditory, and tactile sensory modalities (Golden, 1978). For example, problems in speech and writing can be produced by a failure of the complex perceptual-motor feedback loop. Lesions in the parietal temporal occipital region can produce difficulties in reading, arithmetic, writing, naming, color labeling, and spelling. Verbal memory deficits associated with the left parietal lobe are usually difficulties in organizing the verbal material (Luria, 1973).

The right parietal lobe is associated with the combining of diverse visual, auditory, and tactile information into nonlanguage related wholes. For example, the perception of faces and the drawing of spatially accurate figures are thought to be dependent upon the right parietal lobe. Arithmetic operations where numbers must maintain a place value can also be impaired. The most common symptoms of impairment relate to difficulties dressing and problems relating to the left side of the person's body. This last problem can include neglect of the left visual field (Lezak, 1983).

Occipital Lobes. Visual functions are mediated by the occipital lobes. The occipital lobe in each cerebral hemisphere perceives the contralateral visual field.

The left occipital lobe is important in the visual discrimination and analysis of language-related visual forms, such as letters, words, and numbers. Problems can include an inability to integrate visual stimuli into a coherent whole or to comprehend multiple aspects of a visual form (Luria, 1966). Such visual problems can contribute to difficulties with reading, writing, and arithmetic (Lezak, 1983).

The right occipital lobe is responsible for the visual perception of nonverbal forms. Impairment of this lobe will produce difficulties in the visual recognition and differentiation of forms and unfamiliar patterns (Golden, 1976; Lezak, 1983). Problems in differentiating color hues as opposed to verbally labeling the colors is likely to be a result of right occipital lobe lesions (Scotti & Spinner, 1970).

Neuropsychological Recovery

The *Kennard Principle,* usually mentioned in discussions of brain damage in childhood (Rudel, 1978), proposes that if one sustains a brain injury, it is best to have it earlier in life, because early brain injuries are less disruptive to behavioral function. Rourke, Bakker, Fisk, and Strang (1983), however, point out that there is evidence incompatible with the Kennard Principle. They suggest that the effects of early brain damage are multidetermined by such factors as the type of injury, the location of the lesion, the extent of the brain damage, and the developmental course of the injury. This is not, of course, suggesting that the age at which a lesion occurs does not have an effect, but rather to stress the large number of other factors that warrant consideration (Scheider, 1979).

Teuber and Rudel (1962) illustrated many unique aspects of recovery of function by brain-damaged children. This study utilized brain-damaged adults and children with age appropriate controls and was continued for 10 years to assess the effects of early brain damage on new learning. The brain-damaged children were followed from age 5 to age 15. Three possible developmental patterns of neuropsychological deficit were postulated. These were as follows: (1) There could be initial impairment of behavioral abilities following each brain injury in a child, but the child would show a progressive pattern of recovery over time; (2) there would be impairment of behavioral abilities following early brain injury in a child, and this impairment would be constant as the child matures; and (3) there would *not* be discernible impairments of behavioral abilities following early brain injury, but as the brain-injured child matures, the behavioral deficits arise. The third case represents delayed onset of impairment in the child's abilities. As could be expected, brain-damaged children and brain-damaged adults did not demonstrate the same set of patterns over a number of tasks (Teuber & Rudel, 1962), but rather brain-damaged children displayed all three patterns, depending on the task assessed.

The effects of early brain damage are quite complex. It may depend upon the task under study and the normal developmental sequence of that task, among other factors. It is possible that similar behavioral performances might be accomplished by different groups of neurological structures at different phases of the developmental process.

Recovery after Head Injury in Children

Some special attention will be devoted to the recovery of behavioral functions after head injury in children. Pediatric head injury has received research attention, but there are few studies that are comprehensive (Klonoff, Crockett, & Clark, 1984). Perhaps the best designed series of investigations has been done by a multidisciplinary group of researchers at the University of British Columbia (Klonoff & Low, 1974; Klonoff & Paris, 1974; Klonoff, Low, & Clark, 1977). The University of British Columbia research is a model for others in this area. It included a large number of head-injured children, examined by neurologists, neurosurgeons, neuropsychologists, and psychiatrists on an extensive set of demographic education and health-related variables. Such a data set is warranted, as head injuries are the most common neurological problem in the pediatric age group; head injuries result in 15% of the deaths in the 15 to 24-year-old age group (Klonoff, Crockett, & Clark, 1984).

Some of the most interesting findings are related to the neuropsychological course of recovery. The subjects were followed for five years and were divided into younger (ages 3 to 8) and older (ages 9 to 15) groups. There was a parallel pattern of recovery for both groups with the most marked improvement taking place in the first two years post-injury. There was evidence for significant improvements up to five years after head injury. The older head-injured child had a higher degree of residual neuropsychological impairment after five years (Klonoff, Crockett, & Clark, 1984). Some selected findings regarding the effects of head injury in children are as follows:

1. Boys are more likely than girls to suffer a head injury.
2. Lifestyle variables (congested residential area, lower income housing, marital instability, and occupational status of father) are related to the rate of head injury.
3. After head injury, younger children exhibit irritability and personality changes, while older children demonstrate headaches, dizzy spells, impaired memory, and problems in learning (Klonoff, Crockett, & Clark, 1984).

Intellectual variables are of particular interest in head-injured children. Inspection of IQ data (i.e., Stanford-Binet Intelligence Scale data for children less than five and age appropriate Wechsler Intelligence Scale for children ages five to nine) reveals that the brain-injured children were significantly lower in intelligence than the normal control subjects during the entire five-year study. The most marked differences were at the initial and one-year-later assessments. Also, the IQ variable recovered more rapidly than the neuropsychological variable, suggesting that different domains of adaptive ability were being measured. As a whole, the results would strongly indicate that IQ is influenced by brain injury, and it would be foolhardy to utilize IQ as a matching variable with control suspects (Klonoff, Crockett, & Clark, 1984).

The prediction of neurological sequelae of childhood brain trauma is an important factor in child management. In the British Columbia research, it was found that the full-scale IQ from the initial testing session was the best single predictor of neurological sequelae. Other predictors included period of unconsciousness, post-traumatic amnesia, EEG rating, neurological rating, gestation period, retrograde amnesia, and age (Klonoff, Crockett, & Clark, 1984). Residual neuropsychological status after five years was best predicted by initial full-scale IQ, period of unconsciousness, and post-traumatic amnesia (Klonoff, Crockett, & Clark, 1984).

It is clear from the aforementioned that the IQ variable is of particular significance in studies of head-injured children. As previously noted, children and adults are different neuropsychological populations and attempts to blindly extrapolate findings from one to the other population are uniformed at best and dangerous at worst.

Neuropsychological Patterns

One of the most difficult aspects of child neuropsychology relates to the last of the patterns found by Teuber and Rudel (1962). The fact that certain tasks can become better predictors of brain damage as the brain-damaged child matures suggests that some abilities only emerge in a developmental sequence. It also suggests that prior to a certain age predictions about neuropsychological deficits that would be present at that age would be rash. Bolter and Long (1985) in discussing such delayed onset of behavioral impairment suggested that:

> One possible explanation is that the lesioned area is either functionally immature or not utilized at the time of the insult. When the function assumes dependency on the damaged neural region at a specific point in developmental maturation, the weakness in the system becomes apparent through the appearance of a functional deficit. This supposition does appear consistent with our knowledge regarding the development of the central nervous system (CNS). (p. 45)

The decade-long research study of Teuber and Rudel (1962) illustrates the need to consider neuropsychological deficits in brain-injured children in the content of the child's developmental age. Another important implication is the need for neuropsychological assessment batteries for children which include a broad range of human abilities (Bolter & Long, 1985).

Assessment

Once models and issues regarding neuropsychological function, damage, and recovery are understood, neuropsychologists can proceed with specific procedural considerations involved in the assessment of brain function in children. The following section will address: (1) interview assessment and (2) psychometric tests and batteries.

Interview Assessment

In clinical child neuropsychology, paramount attention is focused upon neuropsychological testing procedures. The majority of articles in research journals publishing papers pertaining to child neuropsychological testing are based on neuropsychological testing. Little research attention is devoted to interviewing in clinical child neuropsychology. This is an unfortunate situation, because the clinical use of the interview is invaluable in assessment when used in conjunction with child neuropsychological testing.

Child Interviewing

As noted by others (Kendall & Braswell, 1985) few children refer themselves. Still, it is a truism that children in their own way can tell a unique version of the truth. How the child sees his or her problem, or, sometimes even more importantly, does not see a problem can be invaluable information to use in designing an intervention. Eliciting information can be done in a number of ways. One of the simplest would be for the examiner to speak to the child and request information (Karoly, 1977). Another method would be, with very young children, to use puppets such as those used in DUSO kits (Dinkmeyer, 1973).

Another issue pertains to the kind of information gathered. In addition to the chief complaints or problems as seen by the child, other important information includes school subjects liked and disliked; relationships with parents, peers, and siblings; sports, and other leisure time activities (i.e., movies and television programs preferred). One very helpful device is to ask the child what he or she would wish for if given three wishes. The nonspecific and fantasy aspect of this request enables the child to project his or her own desires on this task.

It is worth recalling that A. R. Luria (1966) always conducted a "preliminary conversation" before doing any neuropsychological testing. He made the point that this conversation would serve to guide his thinking in the assessment process.

Parent Interviewing

It is important to question the parent so that the child's problems can be precisely described in terms of specific behaviors, antecedent conditions, and behavioral consequences (Kendall & Braswell, 1985). Specific content areas should be examined. In addition to the current complaint or problem, relevant areas would include emotional functioning, social relations, health history, educational history, school adjustment, intellectual abilities, leisure time activities, and family history of psychiatric and medical illness, educational, and vocational status.

One possible means of dealing with the need for comprehensive coverage in little time is to make use of written questionnaires supplemented by a verbal discussion concerning the answers to the questions. This allows the parents to have written records of their answers in their own handwriting. Often, a written record can be very helpful in a later parent conference if there are questions about who disclosed what information.

Neuropsychological Testing

Due to limitations of space, the primary focus of this section will be on precomposed child neuropsychology test batteries. This decision is based on the assumption that the multitest nature of these child neuropsychology batteries will be more appropriate for the description of multifaceted patterns of strengths and weaknesses exhibited by brain-impaired children. The specific child neuropsychology batteries selected for attention are the: (1) Halstead-Reitan Neuropsychology Test Batteries for Children, (2) Luria-Nebraska Neuropsychology-Children's Revision, and (3) Kaufman Assessment Battery for Children.

Halstead-Reitan Neuropsychology Test Batteries

The Halstead-Reitan Neuropsychology Test Batteries for Children are the direct age extension of the adult Halstead-Reitan neuropsychology battery (Reitan & Davison, 1974). Often the Halstead-Reitan neuropsychology test batteries for children and adults are referred to incorrectly. There are actually two separate neuropsychology test batteries for children derived from the work of Halstead and Reitan. The two batteries cover the 5 to 8 and 9 to 14 age ranges. The older children's battery is correctly termed the Halstead Neuropsychology Test Battery for Children (Reitan & Davison, 1974). Children older than 14 can usually be assessed with the adult battery. The younger children's battery is correctly termed the Reitan-Indiana Neuropsychology Test Battery for Children (Reitan & Davison, 1974). At present, there is not a downward extension below age 5 (Selz, 1981).

Reitan modified and added to Halstead's adult neuropsychology battery and developed the two aforementioned neuropsychology test batteries for older and younger children. These test batteries have a number of characteristics in common (Selz, 1981). They first examine a wide range of neuropsychology abilities. Second, the test batteries are capable of reflecting both general and specific effects of brain injury. Third, the test batteries are organized so that multiple methods of interference (i.e., not just levels of performance) can be utilized (Reitan, 1974).

The Halstead-Reitan neuropsychological test battery for children is composed of the following tests. The *category test* was devised to assess concept formation skills. The child inspects a series of slides and selects a response option between 1 and 4 for each slide. On the basis of feedback indicating correct and incorrect answers, the child is expected to deduce the correct principle on which the stimuli on the slides are organized.

The *tactual performance test* was devised to assess nonvisual aided tactile form discrimination and tactile based psychomotor problem solving. The child is blindfolded and placed before a form board with wooden blocks in front of the form board. The child's task is to fit the blocks into the board using only tactile cues, and does so three times. First, he or she uses the preferred hand; second, he or she uses the nonpreferred hand; and on the third trial, both hands can be used. After the three trials, the board is taken away, the child's blindfold is removed, and he or she is requested to draw the form board and put the shapes in their proper location.

The *rhythm test* and *speech sounds perception test* are both measures of auditory skills. The rhythm test was devised to assess perception of different rhythmic sequences. It is also sensitive to attentional deficits. The speech sounds perception test was devised to assess the ability to discriminate speech sounds. On the rhythm test, the stimuli are taperecorded pairs of rhythmic beats and the response option is "same" or "different." On the speech perception test, the stimuli are taperecorded nonsense words. The child responds by underlining from four printed alternatives the word that matches the taperecorded stimulus. *Finger Tapping* was devised to assess motor speed. The child taps a special mechanical apparatus with the preferred and nonpreferred index fingers for five 10-second trials for each hand.

The *tactile, auditory, and visual perception test* was devised to assess sensory stimulation in multiple modalities. The format is the same for each modality. First, four separate trials of sensory perception are randomly presented on a unilateral basis. Then four bilateral simultaneous stimulation trials are presented, again randomly interspersed with unilateral stimulation trials. For the tactile modality, the stimulus is a finger touch. For the auditory modality, the sound stimulus is produced by rubbing fingers together. For the visual modality, the stimulus is a slight movement of the fingers at three height levels (i.e., above shoulders, shoulder, at waist), while the child is asked to focus his or her eyes on the examiner's nose from a distance of three feet.

The *tactile finger recognition test, the fingertip number writing test* and *tactile form recognition test* are measures of tactile discrimination. The format varies from identifying which finger was touched, or a number written on a fingertip or a plastic shape (i.e., cross, circle, square, triangle) placed in the palm of the child's hand.

Aphasia screening test is a measure of language skills. Areas assessed include reading, spelling, speaking, repeating, arithmetic, comprehending, writing, and drawing shapes. Items are at a low level of difficulty.

Strength of grip test is a measure of motor strength. The child grips a hand dynamometer for two alternating trials with each hand.

Trail making test is a measure of visual search and cognitive flexibility. The test consists of two parts. Each part (i.e., A and B) consists of circles arranged on a sheet of paper. Part A has numbers in each circle. Part B has numbers and letters. For part A, the task is to connect the numbers in order. By contrast, on part B, the task is to alternately connect the numbers and letters in sequence.

Lateral dominance examination is a test of lateral preference. It consists of tasks requiring the child to demonstrate right or left hand usage.

The *Reitan-Indiana neuropsychology test battery for children* contains a number of tests from the Halstead neuropsychology test battery for children, but simplified for younger children. These tests include the category test; the tactual performance test; finger tapping test; aphasia screening test; tactile, auditory, and visual perception test; tactile finger recognition test; fingertip symbol writing test (i.e., uses X and O rather than numbers); tactile form recognition test; strength of grip test; and lateral dominance examination. Reitan, realizing that there was a need for additional assessment instruments to use with this 5–8 age range, developed a number of new test procedures. These are the following: the *color form test, progressive figures test,* and *matching pictures test.* These tests were developed to measure conceptual ability and mental flexibility. On the color form test, geometric shapes of different colors are arranged on a sheet of paper. Like part B of the trail making test, the task is to alternately connect colors and shapes. The progressive figures test is an extension of the color form test. On a sheet of paper, various geometric shapes are within other geometric shapes. The task is to connect similar geometric figures. For example, the child might start on a large square with a small circle inside and then move to a large circle. The matching pictures test is a simple matching to sample task.

The *target test* and *individual performance tests* measure the perception and reproduction of visual-spatial abilities. On the target test, the stimulus material is a large sheet with nine dots. The child is given an answer sheet with the same nine dots in any array. The examiner touches the dots on the large sheet in a sequence and then the child is asked to reproduce the examiner's sequence on the answer sheet. The individual performance test is composed of the following four subtests: Matching Vs, star, matching figures, and concentric squares. On the matching Vs, the task is to match Vs on blocks with Vs on a strip of cardboard. On the star, the task is to draw a star made up of two overlapping triangles. On matching figures, the task is to match figures on blocks and figures on strip of cardboard. On concentric squares, the task is to draw a figure made up of three concentric squares.

The *marching test* was developed to assess motor coordination skills. The test has two sections. On the first, the stimulus material consists of a sheet of paper with two sets of circles connected by two lines. The task on the first section is to mark each circle with a crayon in sequence. On the second, the task is to "match" up the two sets of circles and touch the circles with index fingers modeling the examiner in sequence.

These neuropsychological test batteries are extensive and require a considerable amount of time to administer. Also, the age-appropriate Wechsler Intelligence scale is given in conjunction with either Halstead's neuropsychology test battery for children or the Reitan-Indiana neuropsychology test battery for children (Reitan, 1969).

Perhaps the most significant methodological achievement of Ralph M. Reitan was his development of multiple methods of inferring brain damage from neuropsychological test scores of children and adults (Reitan, 1974). Using multiple methods of inference, Reitan was able to cross-validate his clinical hypotheses within the context of a single individual's test protocol. The four methods of inference were: (1) level of performance, (2) pattern of performance, (3) pathognomonic signs, and (4) comparative efficiency of the two sides of the body. These are described next.

Level of performance refers to a child's performance relative to his or her normative group. Simply put, it describes a child as superior, average, or below average relative to age-peers. It is the usual way that psychological tests are interpreted.

Pattern of performance refers to a configuration of test scores. For example, a child may do poorly on measures of verbal concept formation but very well on the tactual performance test. Such a pattern is sometimes found in individuals with a history of antisocial acts.

Pathognomonic signs refers to errors that are rarely, if ever, made by anyone with a normal brain. For example, aphasia is a pathognomonic sign.

Comparative efficiency of the two sides of the body refers to using one side of the body as a control for the other. This is potentially the richest source of hypotheses of subtle cerebral dysfunction. Measures of motor and sensory ability are administered to both sides of the body so it is possible to have one side of the body to serve as a control for the other. Normal expectations are that the dominant side (i.e., the right side in the majority of cases) will be 10% better than the nondominant side. Therefore, a lack of the expected difference or more than the expected difference are valid causes for questioning why this condition arose.

Research Findings

The majority of research studies conducted by Reitan, his co-workers, and doctoral students focused upon separating brain-damaged from normal children.

With respect to determination of brain damage in other children age 9–14, there is ample evidence that the Halstead neuropsychological test battery for children is effective for this purpose. Research (Klonoff & Low, 1974) has reported a hit rate of 85% (i.e., 90% in normal and 80% in brain-damaged children) using multivariate statistical techniques. This result confirmed earlier research (Reed, Reitan, & Klone, 1965; Boll & Reitan, 1972; Boll, 1974), which also demonstrated significant statistical differences.

In terms of particular test measures, the results for children are different from those obtained with adults. The age appropriate Wechsler scales were the most sensitive discriminator of brain impairment for children in the 9–14 age range. Of the non-Wechsler scales measures, the trail making test, finger tapping test, and speech sounds perception test were most effective (Boll, 1974).

On the Reitan-Indiana neuropsychological test battery for children, significant differences were found between brain-damaged and normal children in 5–8 age range. Researchers (Klonoff, Robinson, & Thompson, 1969) found hit rates ranging from 80% (i.e., for five year olds) to 96% (i.e., for eight year olds), while Reitan (1971) in a later study also demonstrated a 70–80% hit rate. A further study (Klonoff & Low, 1974) found comparable results (i.e., 80% hit rates in normal children and 75% in brain-damaged children). Reitan (1974) demonstrated significant differences on almost every measure of the neuropsychological test battery. In a more recent study, Reitan and Herring (1985) reported that screening measures of general neuropsychological abilities and motor measures were more effective in discriminating normal from brain-impaired children.

In terms of individual measures, there are some similarities with the older children. Once again, the age-appropriate Wechsler proved the most effective means of predicting group membership. When the Wechsler scales are not considered then the most sensitive measures on the neuropsychology test battery are the tactile form recognition test, the tactile finger recognition test, the progressive figures test, and the matching test.

It is noteworthy that problem-solving measures (i.e., trail making test and progressive figures) and motor speed skills (finger tapping and marching test) are important in both age groups, but the younger group demonstrated the tactile perception measures (tactile form recognition, tactile finger recognition) were the most sensitive, while the older age group had an auditory perception measure (speech sounds perception test) as the most sensitive. This could reflect the increasing importance of language ability as the child matures.

In terms of learning problems that are neuropsychologically based, Selz and Reitan (1979) were able to discriminate learning disabled, brain-damaged, and normal children in the 9–14 age range at a 73% hit rate using a set of interpretative rules based on the aforementioned four methods of inference.

Luria-Nebraska Neuropsychology Battery—Children's Revision

The Luria-Nebraska Neuropsychology Battery-Children's Revision (LNNB-CR) is a downward extension of the adult version of the Luria-Nebraska Neuropsychology Battery (LNNB) (Golden, Purisch, & Hammeke, 1982). The LNNB-CR is designed for children in the 8–12 age range. Older children may be assessed with the adult LNNB. At present, there is not a LNNB version appropriate for children under age 8. There have been some reports, however, that a life-span Luria neuropsychology examination (Golden, 1986) is under development and will be appropriate for age 2 to the very elderly.

The LNNB-CR is made up of 149 separate items arranged in 11 clinical scales. The items and scale organization, just as in the LNNB, are drawn directly from Luria's (1966) descriptions of his testing procedures in *higher cortical functions in man* and Christensen's (1975) *Luria's neuropsychological investigation.* The scales are titled as follows: motor, rhythm, tactile, visual, receptive speech, expressive speech, writing, reading, arithmetic, memory, and intellectual processes.

The *motor* scale includes items assessing motor speed, coordination, as well as binesthetic movement and drawing geometric shapes. It is the longest single scale (Golden, 1987). As in all of the LNNB-CR scales, its items tap a variety of skills in a single context area.

The *rhythm* scale assesses the child's ability to appreciate and produce musical sounds. These include tonal discrimination, singing songs, and reproducing rhythmic patterns.

The *tactile* scale deals with aspects of tactile perception. Specific items include finger localization, two-point discrimination, and stereognostic skills.

The *visual* scale assesses a variety of visual and visuo-spatial skills. These include the visual identification of objects, pictures, observed figures, and mental rotation of figures.

The *receptive speech* scale deals with the comprehension of spoken language. Specific items include speech sound analysis, understanding simple instructions, and carrying out visual-verbal instructions.

The *expressive speech* scale evaluates the child's ability to produce oral language. Items include repeating words and sentences, automatic speech, naming, and speaking in response to stimuli.

The *writing* scale measures spelling and motor writing skills. The actual items include analysis of words, spelling, and writing from visual and oral stimuli.

The *arithmetic* scale measures simple mathematics skills. The component skills include number recognition, number comparison, and elementary mathematics calculations.

The *memory* scale includes verbal and nonverbal skills. Specific items include word list learning, visual memory, verbal memory with homogeneous or heterogeneous interference, paragraph remembering, and visual-verbal paired associates.

The *intellectual processes* scale was intended to assess general intelligence. Item content covers many skills similar to those on the Wechsler Intelligence Scale for Children—Revised (WISC-R). These include vocabulary, interpretation of pictures and stories, picture arrangement, comprehension of paragraphs, and solving simple arithmetic problems.

In addition to the clinical scales based on content domains established by Luria, Golden developed summary scales for the LNNB-CR. Just as on the LNNB, the *pathognomonic scale* is made up of items that best discriminate normal and brain-damaged children.

The *left* and *right sensorimotor* scales are used to lateralize brain damage in the sensory-motor region. The sensorimotor scales are made up of items from opposite side motor and tactile scale items (Golden, 1987).

Just as with the LNNB, each item of the LNNB-CR is considered a separate test. Criteria for scoring include speed of response, number of responses, response latency, correctness of response, and learning ability. Responses are scaled on a 0–2 ordinal scale. Scores of 0 indicate a normal limits performance, scores of 1 are borderline and scores of 2 are taken as a performance suggesting brain damage (Golden, 1987).

One of the most interesting aspects of the LNNB-CR is that, like the LNNB, it is similar in format to the Minnesota Multiphasic Personality Inventory (MMPI). Each item can be combined with others to devise new scales (McKay & Golden, 1979). Therefore, the development of new scales is limited only to creative imaginative and empirical considerations. Moreover, the LNNB-CR scale raw scores are transformed into T-score scales ($X = 50$, $SD = 10$). This facilitates comparison between and among scales (Golden, 1987).

As with the LNNB, the LNNB-CR has been subject to a number of research investigations (Golden, 1987). These studies have demonstrated the value of the LNNB-CR in child clinical neuropsychology. The results of some of these studies will be briefly mentioned. The studies will be discussed with respect to the differentiation of brain-damaged and normal children, the ability of the LNNB to distinguish the learning disabled children from others, and the relationship of the LNNB-CR to other selected measures used in child clinical neuropsychology (i.e., Halstead's Neuropsychology Battery for Children and the Wechsler Intelligence Scale for Children).

The first studies of the LNNB-CR concentrated on the discrimination of brain-damaged children from normal children. As would seem obvious, this is the primary task of a child clinical neuropsychology battery and the acid test of its worth to the pediatric neurologist, child psychiatrist, and school psychologist, among others. Greta N. Wilkening, Psy.D., who worked with Golden to devise the LNNB-CR, performed the initial validation study (Wilkening, Golden, MacInnes, Plaisted, & Hermann, 1981).

In this study, 76 brain-damaged children and 126 normal children were studied. The LNNB-CR had a hit rate of 82% (i.e., 91% normal children, 65% brain-damaged children). Similar studies by Gustavson, Golden, Leark, Wilkening, Hermann, and Plaisted (1982) and Gustavson, Golden, Wilkening, Hermann, Plaisted, MacInnes, and Leark (1984) also found that the LNNB-CR could effectively differentiate brain-damaged children from normal children. In the Gustavson et al. (1984) study, the authors obtained a hit rate of 87%, (i.e., 93% normal children, 78% brain-damaged children). These values were essentially the same as those obtained by Wilkening (Wilkening et al., 1981) and her colleagues in the initial study. Carr, Sweet, and Rossini (1986) reported, however, that the LNNB-CR was no more useful in discriminating psychiatric and neurological subjects than the WISC-R.

Another important test for the LNNB-CR is its ability to identify learning disabled children. A number of studies addressed this issue. Nolan, Hammeke, and Barkley (1983) compared 3 groups, of 12 children each with mathematics disabilities, reading and spelling disabilities, and no disability based on the Wide Range Achievement Test (WRAT). All children had scores of 80 or higher on the WISC-R. The reading and spelling disabled group was significantly lower than the normal or mathematics disabled groups on expressive speech, writing, and reading scales. There were no significant differences between the normal and the mathematics disabled groups, contrary to expectations.

Geary, Jennings, Schultz, and Alper (1984) also assessed the ability of the LNNB-CR to discriminate learning disabled children from normal children. In this study, there were two groups of 15 children each: (1) learning disabled children and (2) normal children. The LNNB-CR had a hit rate of 93% (i.e., 100% learning disabled children, 86.7% normal children). Geary and Gilger (1984) used a similar design but had 2 groups of 17 children (one learning disabled and the other normal). The groups were significantly different on the expressive speech, writing, reading, and rhythm scales of the LNNB-CR.

In a study utilizing the same sort of design as the two Geary et al. studies, Teeter and Malsch (1984) also assessed the ability of the LNNB-CR to discriminate learning disabled children from normal children. In this study, the LNNB-CR was able to produce a hit rate of 96% for the learning disabled children and 93% for the normal children.

In still another study on the discrimination of learning disabled children from normal children with the LNNB-CR, Hyman (1984) found significant differences on all clinical scales. In marked contrast from the other studies, Morgan and Brown (1988) were unable to find significant differences on the LNNB-CR among groups of learning disabled children divided into three groups based on verbal and performance IQ difference of the WISC-R. A limitation of the study was that the groups were not assessed on academic skill patterns. Different groupings could lead to different results. Another recent study (Schaughency, Lahey, Hynd, Stone, Piacentini, & Frick, 1989) failed to find differences on the LNNB-CR for groups of children with attention deficit disorder without hyperactivity (ADD) or attention deficit disorder with hyperactivity ADHD). The results from these studies appear to suggest that the LNNB-CR may be capable of distinguishing groups of learning disabled children from groups of normal children. How valuable the LNNB-CR is to differentiate subtypes of learning disabled children, or ADD vs. ADHD children however, is a question that warrants further research.

Kaufman Assessment Battery for Children (K-ABC)

One additional neuropsychology test battery that deserves comment at this time is the K-ABC (Kaufman & Kaufman, 1983, a, b, c,). It is newer than the LNNB-CR but in a short time has generated a considerable body of research data.

In devising the K-ABC, the Kaufmans' utilized recent research advances in the assessment of human mental abilities. The K-ABC is constructed on a paradigm of sequential and simultaneous information processing (Reynolds & Kamphaus, 1986). This theoretical base was gleamed from research in neuropsychology (Luria, 1966), cerebral specialization (Sperry, 1961), and cognitive psychology (Neisser, 1967), which has been developed over a number of years.

Simultaneous and sequential processing are seen by the Kaufmans as separate mental abilities. Simultaneous processing requires the child to put diverse bits of information together at the same time to solve a problem. Spatial organizational abilities are often cited as examples. On the WISC-R, for example, the block design subtest would be a model for a thinking skill. By contrast, sequential processing requires the child to put the bits of information in serial order in order to solve a problem. The bits of information are organized in a temporal or linear sequence. The difference between the two parts of mental abilities are similar to driving a car in heavy traffic (simultaneous) versus using a cookbook to bake a cake (sequential).

It might be mentioned that children's brains usually work by utilizing both types of information processing, but that usually one or the other approach predominates (Reynolds & Kamphaus, 1986).

In terms of test construction, the K-ABC is an excellent model to emulate in neuropsychology. The test manual is well-written, normative data are extensive, and the test materials are well-designed. The K-ABC has five global scales. Included are: *sequential processing, mental processing, compositive, achievement* and *nonverbal*. The *sequential processing* and *simultaneous processing scale* are measures of constructs that were previously described. The *mental processing scale* is a summary scale that combines both sequential and simultaneous processing. The *achievement scale* is a measure of what the child knows. It includes verbal skills (i.e., vocabulary) and school subjects, (i.e., reading, math). The achievement scale could be considered a measure of the child's success in learning about his or her world to date (Reynolds & Kamphaus, 1986).

The *nonverbal scale* is a short form of the *mental processing scale*, which can be administered without using verbal instructions or responses (Kaufman & Kaufman, 1983b, c). All of these global scales are transformed into standard scores, with a mean of 100 and a standard deviation of 15, just like the age-appropriate Wechsler scales (Kaufman & Kaufman, 1983a). The K-ABC has a total of 16 subtests, but only certain ones are given at any age. The largest number (13) are given to children aged 7 to 12½. On the sequential processing scale, the subtest includes *hand movements* (i.e., imitating a series of hand movement), *number recall* (i.e., recalling a series of numbers), and *word order* (i.e., recalling a series of pictures) (Reynolds & Kamphaus, 1986).

On the simultaneous processing scale, the subtests again reflect the core mental ability assessed by the scale. These include *magic window* (i.e., identifying a picture after seeing portions), *face recognition* (i.e., recognizing a face seen before), *Gestalt closure* (i.e., identifying an obscured object), *triangles* (i.e., assembling triangles to match a model), *matrix analogies* (i.e., selecting a picture to complete a verbal model), *spatial memory* (i.e., recalling the location of pictures on a page), and *photo series* (i.e., arranging photographics in chronological order) (Reynolds & Kamphaus, 1986). In the achievement scale, the subtests include the following *expressive vocabulary* (i.e., naming objects), *faces and places* (i.e., naming persons or places), *arithmetic* (i.e., number manipulation or math concepts), *riddles* (i.e., deductive reasoning), *reading/decoding* (i.e., reading words and letters), and *reading/understanding* (i.e., follow written instructions).

In terms of its use in neuropsychology, the K-ABC has the best standardization of any assessment device in child clinical neuropsychology,

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with the possible exception of the age-appropriate Wechsler scale. The K-ABC sample was matched on major demographic variables according to the 1980 U.S. census figures and included 2,000 children (Kaufman & Kaufman, 1983a).

In terms of usefulness for neuropsychology, studies of the K-ABC have focused on specific applications. Telzrow, Redmond, and Zimmerman (1984) examined the relationship of the K-ABC to Broder's subtypes of reading disability. They found clear relationships on the K-ABC in line with theory predictions. In a separate study, Morris and Bigler (1985) explained the relationship of K-ABC and children with left and right hemisphere neuropsychology deficits. They demonstrated clear relationships between the K-ABC simultaneous and sequential scales and lateralized neuropsychological impairment that were consistent with theoretical predictions. Another area of interest is the relationship of the K-ABC with more established measures in child neuropsychology, such as the WISC-R and LNNB-CR. With respect to the WISC-R, well-designed studies (Kaufman & Kaufman, 1983a) have demonstrated a high correlation between WISC-R full scale IQ and the K-ABC mental processing composite. One study of normal children found a correlation of .70.

With respect to the LNNB-CR, two studies (Snyder, Leark, Golden, Grove, & Allison, 1983) explored the relationship between the K-ABC and LNNB-CR. In the first study (Snyder et al., 1983), the pattern of correlation demonstrated considerable shared variance between the K-ABC mental processing composite and the LNNB-CR intellectual processes scale (i.e., .64).

The conclusion was that the K-ABC was consistent with Luria's theoretical paradigm and also provided additional information to the LNNB-CR.

In the second study (Leark et al., 1983), these impressions were further supported. Once again the LNNB-CR intelligence scales had the highest correlation with the K-ABC mental processing composite. Additionally, similar high correlations of the LNNB-Pathognomic scale with nonverbal, achievement, and sequential scales suggest the K-ABC is sensitive to brain damage (Reynolds & Kamphaus, 1986). It would appear that more research in child clinical neuropsychology is clearly warranted on this well-constructed and standardized test battery.

The K-ABC has singular advantages for guiding educational interventions with brain-damaged and learning disabled children (Reynolds & Kamphaus, 1986). For example, in the *K-ABC Interpretive Manual* (Kaufman & Kaufman, 1983a), a model for utilizing the child's neuropsychological strengths to plan educational programs is presented. The particular advantage of the K-ABC is that it provides a clear framework for guiding a strengths model of remediation (Reynolds, 1981). Hartlage and

Telzrow (1986) suggest that the development of compensatory skills based upon the child's neuropsychological strengths holds the greatest promise to remediate educationally troubled children suffering from either structural brain damage and/or learning disabilities. The hope and expectation is that further research with the K-ABC will show greater progress in molding the unique ability structure assessment of the K-ABC and validity strengths model of neuropsychological intervention (Reynolds, 1981).

Summary

In this chapter, the focus has been upon major neuropsychological test batteries utilized in clinical child neuropsychology. The test batteries considered were the age appropriate Halstead-Reitan procedures (i.e., Halstead's Neuropsychological Battery for Children, Reitan-Indiana Neuropsychology Battery for Children), the Luria-Nebraska Neuropsychology Battery-Children's Revision, and the Kaufman-Assessment Battery for Children. Each of these procedures was placed in historical context, its structure considered, and the empirical evidence reviewed.

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