

**ASSESSMENT AND TREATMENT OF IMPAIRED EXECUTIVE
FUNCTIONS IN CHILDREN WITH TRAUMATIC BRAIN INJURY**

by

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Abstract

The maturational course of the development of executive functioning abilities is dependent on functional capacity of the human brain. Unfortunately there is a dearth of standardized functional assessments of executive functioning abilities for children. The present paper describes neurodevelopment of executive functioning and several recent measures of executive functioning that have been developed to assess maturational periods of specific executive functions. Clinical implications of these results for traumatically brain injured children are described

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Validity of neuropsychological research findings with neuropsychological assessment intervention methods with children have been impressively demonstrated (Hartlage, 1975, 1986; Horton, 1994; Horton & Puente, 1986; Hynd & Willis, 1988; Reitan & Davidson, 1974; Reynolds & Fletcher-Janzen, 1989). These remarkable demonstrations of neuropsychological assessment methods have engendered great interest in clinical child neuropsychology. Contemporary neurodiagnostic imaging methods such as Positron Emission Tomography or PET-scanning or Magnetic Resonance Imaging (MRI) or Functional Magnetic Resonance Imaging (fMRI) of course, clearly identify structural brain lesions (Roth, Koven & Pendergrass, 2008), but in subtle cases of traumatic brain injury neuroimaging may be inadequate to reflect changes in the physiological functioning of the brain that may result in behavioral problems in the school and home. Neuropathological conditions such as sequella of traumatic brain injury in children may produce neurocognitive, sensory-perceptual and motoric deficits without demonstrating structural brain changes under imaging (Horton & Horton, 2008).

The purpose of this article is to address the importance of assessing executive function in children with traumatic brain injuries and describe methods for assessing executive functions in children (Reynolds & Horton, 2006). The article will discuss the development of executive functions (EFs) as children mature and how these brain-based abilities may be assessed efficiently for clinical and educational purposes. Understanding how children's executive functions develop is of great clinical importance. At the same time, the study of executive functions in children is still in the process of development and much remains to be learned. Few tools for the assessment of executive functions in

children with traumatic brain injury are available (Reynolds, 2003; Reynolds & Horton, 2006). This dearth of assessment measures for EFs in children and adolescents is most unfortunate as EFs are extremely important clinical considerations in neuropsychology practice (Zillmer & Spiers, 2001).

In addition to assessment, executive functions in children have important implications for the treatment of impaired brain functions in children with traumatic brain injuries.

Treatment of EFs in traumatically brain injured children can be assisted by understanding the normal developmental course of their brains. The famous Russian neuropsychologist A. R. Luria (1966), for example noted that the success of rehabilitation of brain functions after traumatic brain injury was mediated by the nature of the brain injured person's residual executive functioning abilities. In addition, there are forensic implications of the development of executive functions in children. If a child lacks a reasonable ability to appreciate the consequences of their actions, the law allows for mitigation of punishment. The decisional ability of a minor accused of a criminal act involves understanding the nature of the minor's EFs decision making abilities. In criminal proceedings where there are serious consequences, an understanding of his or her executive functioning can be crucial. In civil proceedings, a child may have committed acts for which there is legal liability and understanding the developmental course of EFs can assist the court in arriving at an appropriate decision.

Defining Executive Functioning

EFs have been described as include multiple mental functions such decision-making, planning, inhibition, sequencing, development of plans of action and motor outputs, among other mental functions. Lezak (1995) saw executive functions as falling into 4 components: "volition, planning, purposive action, effective performance" (P. 650).

Lezak (1995) said each component "...involves a distinctive set of activity related behaviors" (p.650) and is necessary for successful adaptive self-direction. For example, EFs can be contrasted with the domain of general knowledge. Executive functions can be seen as dealing with planning, monitoring and evaluating behavioral actions to perform adaptive behaviors. On the other hand, general knowledge relates more to maintaining and retrieving an organized set of objective facts. In a nutshell, EF require active planning actions and generating novel motor outputs that are adaptive to external demands rather than the passive retention of various varieties of information domains (Reynolds & Horton, 2006).

Contemporary understanding of brain behavior relationships avers that impairment in brain areas other than the frontal lobes impair EFs (Reitan & Wolfson, 2004). The frontal lobes certainly assist in the coordination of EFs and are clearly involved in self-regulatory behavior, generative behavior, meta-cognition and working memory. Moreover, frontal areas are involved in complex higher mental processes and are essential for the optimal functioning of the human brain as an integrated neurocognitive-system. Luria (1969), for example, described the cerebral coordination of conscious acts as the major task of the frontal lobes. At the same time, EFs are mediated by to the dynamic localization of functioning similar to other higher cognitive processes (Luria, 1969). Even at this time, it is not possible to enumerate the entire range of possible executive functions in children as the range is potentially limitless (Reynolds & Horton, 2006). Only a very limited number of clinical neuropsychological procedures for

assessment of EFs, unfortunately, have been studied thus far by experimental and clinical neuropsychologists and other workers in neuroscience.

Traumatic Brain Injury in Children

Historically, it had been thought that children receive traumatic brain damage early in life tend to show much more recovery of function than those who receive the same trauma at a later age. However, as research in the last century has shown, the relationship is much more complex. In a recent review, Babikian and Asarnow (2009) overall found (using the Glasgow Coma Scale (GCS) to assess severity of traumatic brain injury) that following mild injury (GCS 13-15) there is effectively complete resolution of any impairments, whereas those with moderate injury (GCS 9-12) do improve over time but do not catch up to controls. Those with severe injury (GCS 3-8) not only show early deficits in functioning but also do not show the expected gains with age, and hence become more deficient compared to controls. Although there were individual differences for types of tasks, overall full scale intelligence followed this pattern.

Catroppa, Anderson, Morse, Haritou, and Rosenfeld (2007), looking at young children (mean age slightly under 5 years at time of injury), supported the concept that the severity of the injury is important to outcome (e.g., attention and processing speed) at least up to five years after the brain injury. In addition their results generally supported the contention that those skills which are developing at the time of injury may be more compromised than those which are established, and subsequently may not develop at a normal rate. Not surprisingly, executive functioning can be impaired following early brain trauma. Sesma, Sklomine, Ding, McCarthy, et al. (2008), looking at those between

the ages of 5 and 15 years, found that after a year about a quarter of those with mild and moderate TBI and over 35% of those with severe TBI still exhibited clinically significant executive dysfunction based on a parent rating scale, compared to about 10% for the orthopedic control group. Looking at children with moderate and severe injury with a mean age of about 9.5 years, Max, Koele, Castillo, Lindgren, Arndt, Bokura, Robin, Smith, & Sat (2000) found that behavior problems, as determined by a parental checklist, persisted for at least a year at twice the rate (23%) of the controls (13%) for moderate TBI, and about three times (31%) for severe TBI.

Neurodevelopmental Theory and Executive Functions

Luria's theories (1963, 1966, 1969 and 1973) regarding EF are important conceptual contributions. Luria's EF model postulated specific developmental stages which are related to phases of higher cortical maturation (Horton, 1987). Neurodevelopmental processes in children are clearly different from adult neurodevelopmental processes (Rourke, Fisk, & Strang, 1986). Child brains remain have been less studied than adult brains and there is greater variability in terms of the expression of EF abilities in child brain development (Horton & Puente, 1986). Children are in a continual nonlinear trajectory of functional neurodevelopment as they mature. In addition, specific abnormal learning, developmental, or behavioral processes related to physical illness such as traumatic brain injury can complicate the current and future neurodevelopment of a child. (Hynd & Obrzut, 1981; Hynd & Wills, 1988; Reynolds, 1981).

It is important to remember that the brain processes information, and, hence, it might be helpful to look at executive processing. The prefrontal areas, so critical for executive processing, have reciprocal connections to the secondary and tertiary

cortical sensory areas, areas critical for memory, as well as the more midline areas that are involved in processing affective information. It also has similar connections with the secondary motor areas. There are additional subcortical outputs to the telencephalic and other basal ganglia, very much mirroring the cortically originating extrapyramidal system. This suggests that the prefrontal areas receives sensory, memorial, and affective information, and organizes the data to produce the best motor output. Trauma to the prefrontal area results in the available and essential information not being processed, and the results are various forms of executive dysfunction. Complex neurodevelopmental factors also can complicate the clinical assessment of child neuropsychological abilities such as EF and subtypes of learning disorders (Boder, 1973; Mattis, French, & Rapin, 1975). For example, collecting appropriate large normative samples of child neuropsychological data is extremely difficult logistically and very expensive and time consuming (Hartlage, 1986). Neuropsychological abilities in children also vary in terms of quantity and quality depending on the various neurocognitive developmental stages. Similarly, neuropsychological normative data must be interpreted in terms of understanding the child's neurocognitive development and EF at the various stages on neuropsychological development (Hynd & Willis, 1988; Reynolds, 1981). Clearly, a child must have developed various EF abilities before the child be said to have lost the various EF abilities due to traumatic brain injury, to mention but a single example. Child could have not had the opportunity to acquire a specific EF skill, the problem of the lack of the EF skill was not one related to traumatic brain injury but to inadequate educational opportunities. EF abilities require a developmental progression and can not be said to be

lost to an acquired traumatic brain injury if the EF abilities had not emerged. Damage to brain systems at one neurodevelopmental stage, however, may also have different neurodevelopmental manifestations at a later stage of cortical maturation.

Basic Review of Developmental Neuroanatomy

The brief review below is not a detailed treatment of the neuroanatomy of functional brain-behavior relationships. The reader is referred to other volumes that more fully address developmental neuroanatomy (Kolb & Fantie, 1989; Hynd & Willis, 1988; Reitan & Wolfson, 1992, Spreen, Risser & Edgell, 1995).

Luria (1966) describes the brain as being composed of three units. The first unit is within the brainstem. This area is involved in providing cortical tone, or one could say, arousal, to the other, cortical, areas of the brain. This would include areas like the ascending reticular activating system. The second functional unit is comprised of the cerebral cortex lying posterior to the central sulcus. It is involved in processing sensory information. The third functional unit is the cerebral area anterior to the central sulcus, and its primary function is movement, one could say motor functioning. The second and third units can also be subdivided into primary, secondary, and tertiary cortical zones. The primary zones of the second functional unit process the basic sensory information, visual, auditory, and somesthetic. These are the areas which receive the sensory subcortical input from the thalamus. The secondary cortical zones of the second unit could be called the gnostic zones in that these are the areas where the primary sensory information is organized to

identify objects and their location. The tertiary zones of the second unit lie within the parietal and temporal lobes and are involved in the higher cortical processing of this already processed information. These areas analyze, determine relationships, make cross-modal comparisons, and in general integrate sensory information from various sensory areas. They are also involved in processing emotional and memory information.

The third functional unit is also composed of three zones. The primary zone, lying just anterior to the central sulcus, is the primary motor area. Stimulation to this area sends the information down the spinal cord where it can be transferred to an alpha motor neuron, which causes muscle movement. The secondary zone of the third unit, lying generally anterior to the primary motor zone, is involved in regulating motor movement through aspects such as fine motor control. The tertiary zone of the third unit is involved in gathering information from the rest of the brain to guide the motor movement. With damage to this premotor and cingulate areas, the brain is unable to process all of the available information prior to making a response. The result is executive dysfunction.

Luria (1980) makes the observation that the brain changes over development and the relationships between the different areas also change over the course of development. Early, the primary and secondary sensory processes predominate. Later, as the higher mental functions are being formed, more complex systems of

connections play a major role. Early disruption of basic sensory processes, analysis and integration, may well cause disruption in the adult of many higher cortical functions. The same disruption of basic sensory processes in an adult, once these complex systems have developed, will have less of an effect on the higher functions. He concludes that, "This concept implies that the character of the cortical intercentral relationships does not remain the same at different stages of development of a function and that the effect of a lesion of a particular part of the brain will differ at different stages of functional development" (p. 35).

Luria (1966) also proposed five stages in the functional development of the brain. However, this development is dependent on an interaction of the individual with the physical, interpersonal, and other aspects of the environment. The first stage, beginning in the first year of life, involves the most basic interactions with the environment, including that of arousal, and it is the time of the development of the brain stem structures such as the ascending reticular activating system. This is the initial development of the first unit of the brain.

The second stage involves the development of the primary sensory and motor stages, and, one would assume, the interaction of the sensory and motor areas. The major development here is in the second year of life. During the third stage the secondary areas substantially develop. On the sensory side the child is able to comprehend, recognize, and appreciate the basic natures of the perceived objects as well as their symbolic representations. Similarly, the child is able to orchestrate motor movements in a complex manner and is more able to model

those of others. This stage continues through the preschool age.

The fourth stage begins for most with the onset of school. The posterior tertiary areas, especially of the parietal lobes, develop permitting integration of information across sensory modalities, symbolic and abstract reasoning, the ability to comprehend a perspective other than their own, and a much more full appreciation for the social environment. This stage occurs during the first few years of school. It is the first stage of what could be called higher cortical functioning.

The fifth stage, usually starting at about age eight and continuing through adolescence and into early adulthood, is based on the development of the frontal regions, specifically the prefrontal areas. This development permits complex mental activities such as complex abstract reasoning, intentional and working memory, monitoring and evaluation of personal behavior.

While Luria (1980) provides a theoretical model of the development of executive functioning processes, it is quite apparent to that the neuropsychological development of all children does not follow a uniform pace. Some are a little slower to develop specific skills and others are precocious in this area. Further, it is not uncommon to find that some of those who were slow initially wind up catching up to their peers in a given function, such as reading, and others who were quick out of the blocks who do not maintain that advantage. In addition, not all areas of the brain, especially the tertiary areas, develop at the same pace. As a

result, some children may be slow initially in a selected neuropsychological domain but will later fall within or above age group expectations later in adolescence or adulthood. Another aspect for consideration is that, in accord with what Luria (1980) said about the developmental aspects of traumatic brain injury, an early lesion may preclude the later development of an expected function. For example, a child who suffers substantial brain trauma to an area near the temporal-parietal-occipital junction at age five may be precluded from ever being able to read. However, oral communication, which assumedly was developing prior to the accident, may well be fully functional as the child matures.

Along this line, neuropsychology research (Kolb & Fantie, 1989) has established two developmental phenomena possible after early lesions of the brain, in particular the prefrontal cortex area. The first is an apparent “growing out of” the effects of the lesion. In this case, although there may be deficits at the time of the early trauma, after a period of time there are no deficits, even though identical lesions at a later date can cause severe deficits. The second is an apparent “growing into” the effects of the lesion. This is similar to the child in the accident mentioned above. In this case the deficits consequent to the brain damage are not immediately apparent, but they do develop over time. If one considers the relatively late functional development of the prefrontal areas, it makes sense that following early brain trauma to these areas the deficits may not be immediately apparent for those functions have not yet developed in the undamaged brain. However, after time the normal development of these functions does not appear. In a similar vein, those with perinatal trauma, either through the birth processes itself or related to events prior to the birth may develop executive dysfunctions later in

life.

Meta-Analysis of Executive Functioning Measures

Previously, however, the developmental trajectory of the EF measures on functional measures of EF was unclear. Romine and Reynolds (2005) conducted a Meta-analysis of existing research on the above functional measures of EF. The clear overall finding of the Meta-analysis was a general positive trend of improvement over time as the subjects matured. Most EF abilities included planning and verbal fluency abilities appeared to continue to improve until adulthood. The various EF measures were collapsed across all of the measures and the results can be seen as a positive trend from ages 5 to 14, a flattened line from ages 14 to 17 and then an increased positive slope from age 17 to age 22 (only studies to age 22 were reviewed). EF abilities showed a dose response relationship between increasing age and more developed executive functioning abilities. The extant research on EF in children however, had significant methodological limitations (Romine & Reynolds, such as age limits on some measures, small sample sizes, a lack of continuity of ages across studies, and a lack of continuity across tasks and across studies that severely limited conclusions that could be drawn from the meta-analysis. Nonetheless, the Meta-analysis demonstrated an overall dose response relationship between increasing ages and enhanced EF performance in children. Because of the significant methodological limitations noted by Romine and Reynolds (2005), however, a large, comprehensive and methodologically sophisticated study of the development of executive functioning abilities was conducted (Reynolds & Horton, 2006). The new study assessed a large number of subjects across a wide age range (8 to

89 years) and the executive functioning tasks, included measures of card sorting, verbal fluency and “trail making” (Reynolds, 2003, Reynolds & Horton, 2006). were scored using common scaling so that the results would be easily compared. tests of card sorting, verbal fluency and “trail making” (Reynolds, 2003, Reynolds & Horton, 2006). The “trailmaking: tasks included the Comprehensive Trail Making (CTMT) (Reynolds, 2003) and the Test of Verbal Conceptualization and Fluency (TVCF) that includes a card sorting task, verbal fluency measures (letter and category) and a single “trail making” measure (Reynolds & Horton, 2006). The data demonstrated that various well accepted and widely used measures of EF abilities from the TVCF and CTMT show all demonstrated positive increasing performances during childhood. The data are generally consistent with earlier longitudinal research (Reynolds, Castillo, & Horton, 2008).

Methods of Measurement of Executive Functions

Impairments in brain areas other than the frontal lobes may also impair EF (Reitan & Wolfson, 2004). Neuropsychological tests that assess EFs do not postulate specific localization for any particular brain area as being solely responsible for EF. It would probably be impossible, given the current extent of knowledge regarding EF, for any single measure to sample the entire range of EFs, as the range is unknown. Clinical child neuropsychological research, of necessity, has researched limited sets of measures of EF. The neuropsychological procedures which have thus far been researched as models for EF include card sorting tasks, category and letter retrieval tasks, and “trailmaking” tasks (Reynolds & Horton, 2006).

Card Sorting Tasks

Sorting tests involving blocks and cards have a long history in clinical neuropsychology (Lezak, 1995). The Wisconsin Card Sorting Test (WCST) (Grant & Berg, 1948) was devised to assess the ability to set shift based on abstract thinking (Lezak, 1995). The WCST materials are cards, which are sorted based on the principles of color, form, and number (Heaton, 1981). The person being assessed sorts the cards in to four piles corresponding to each of the four standard stimulus cards (Heaton, 1981). The Heaton scoring system is the most often used (1981) and was later revised and expanded (Heaton, Chelune, Talley, Kay, & Curtiss, 1993). Milner (1963) validated the WCST as a measure of frontal lobe abilities however, later research has produced mixed findings (Lezak, 1995). Rather than solely a measure of frontal lobe abilities, research finding indicate the WCST is a generalized measure of planning ability, (Heaton, 1981) measuring abilities similar to “Tower of London” tasks (Zillmer & Spiers, 2001). WCST Interrater reliability is adequate for clinical use (Axelrod, Goldman, & Woodard, 1992). Demographic effects are minimal until very late in life ((Heaton, Grant, & Matthews, 1991; Lezak, 1995).

Category and Letter Retrieval

Verbal fluency tasks have advantages in assessment of EF (Lezak, 1995). Estes (1974) noted that verbal fluency measures may be used as measures of executive functioning and verbal fluency can be assess by both category and letter retrieval tasks.

Benton assessed (Benton & Hamsher, 1989) letter retrieval and developed the Controlled Oral Word Association Test (COWAT) (Benton and Hamsher, 1989) which uses a set of three letters, “FAS,” for three word naming trials where words that start with a particular letter are named in one minute. The combination of the sum of words from each of the three trials is the score for the test (Benton & Hamsher, 1989). Benton (1968) found that verbal fluency was most impaired for patients with bilateral frontal lobe impairment and for unilateral impairment, the left frontal lobe patients did more poorly than right frontal lobe patients.

Category naming tasks (Rosen, 1980) use category retrieval to assess semantic category organization. The patient is to name, for a minute each, as many items in various categories such as “animals” “items in a super market,” and “fruits,” and “vegetables”, Categorical naming is sensitive to impairment in patents with Alzheimer’s disease (Rosen, 1980) and helps to distinguish between patients with either dementia and depression (Hart, Kwentus, Taylor, & Hamer, 1988).

Trail-Making Tasks

The original Trail Making Test consisted of two tasks, known as Trails A and Trails B. On part A, the examinee connects circled numbers by drawing a line. Trails B provided alternating numbers and letters to be connected in sequence, 1-A-2-B-3-C.... Reitan (e.g., 1955, 1958) demonstrated the TMT was sensitive to brain damage (Reitan & Wolfson, 1993) and other investigators have confirmed this finding (Stuss, Bisschop, Alexander, Levine, Katz,, & Izukawa,2001; Reynolds & Horton, 2006, Lezak, 1995; Mitrushina et al., 1999; Storandt, Botwinick, & Danziger, 1984). To improve the methodological

aspects of the TMT, the Comprehensive Trail Making Test (CTMT) (Reynolds, 2003) was developed to improve reliability while maintaining the sensitivity to brain damage of the original TMT.

Clinical Implications

The major clinical implications will be discussed in terms of assessment, treatment, and forensic recommendations. This categorization is not intended to be exhaustive but rather illustrative of possible areas and other areas and implications could also be considered.

Assessment

Assessment of EF functioning abilities should include multiple methods using a variety of test formats. A minimal set of executive functioning ability measures should include at least one motor reduced task, one motor enhanced task, and one behavioral measure. Put another way, all EF assessments should include a perceptual motor measure (“trail making” task), a classification measure that has minimal perceptual-motor requirement (card sorting task), and a verbal retrieval response measure (letter and category verbal fluency tasks). EF abilities should always be assessed with well standardized neuropsychological tests with excellent psychometric characteristics and the data should be interpreted by using age corrected normative data.

Treatment

EF abilities are at different stages at different ages so lost skills should be aggressively treated at all ages. Aggressive retraining and development of self-regulatory and metacognitive skills is indicated into adulthood (until at least age 30). Self-regulatory skills include attentional skills, impulse control, and social behavior. Functional changes in EF will continue from childhood through adolescence and into adulthood (until at least

age 30). Patient and significant others (e.g., parents, siblings and school officials) should be knowledgeable about developmental changes in EF abilities and implications for changes in learning abilities and everyday behavior. Neuropsychological re-evaluations of EF abilities should be conducted every two years after traumatic brain injury in a child and continue until the child reaches maturity (until at least age 30). The composition of future neuropsychological re-evaluations would depend on the pattern of EF abilities detected by the serial neuropsychological evaluations. Treatment services for EF abilities in traumatically brain injured children should be available through adulthood.

Forensic

The forensic implications of these findings are that structured and related settlements in personal injury cases of children with EF abilities impairment related to traumatic brain injury should incorporate serial longer term neuropsychological assessments and extended treatment costs. Certification of juveniles with traumatic brain injuries as adults for purposes of litigation should give careful consideration of possibly impaired EF skills, especially given their implications for integrity of residual planning and decision making skills. The functional trajectory of EF abilities development does not support the current age of eligibility for the sentence of death in capital cases given the continued development of the neuroanatomical regions of the human brain involved in EF. The functional trajectory of executive functioning abilities neurodevelopment are important mediating factors related the legal concepts of mitigation and future dangerousness.

SUMMARY

Children with traumatic brain injuries that have impaired executive functioning require clinical neuropsychological services and an appreciation of the structure and functioning of the cerebral cortex related to executive functioning will be invaluable in assessment

and treatment. This article presented a very selective review of executive functioning abilities with special attention to children who have suffered traumatic brain injuries. Related to EFs the gross morphology of the central nervous system, Luria's model of brain functioning and assessment of executive functioning abilities, have been described in an admittedly much over simplified and very cursory manner. The hope and expectation is this article will facilitate the delivery of clinical neuropsychological assessment and treatment services to traumatically brain injured children.

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