VALIDATION OF THE EXPANDED MCCARRON-DIAL SYSTEM FOR

DIAGNOSIS OF NEUROPSYCHOLOGICAL

DYSFUNCTION IN ADULTS

DISSERTATION

Presented to the Graduate Council of the

University of North Texas in Partial

Fulfillment of the Requirements

For the Degree of

DOCTOR OF PHILOSOPHY

By

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Denton, Texas

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The McCarron-Dial System (MDS) has successfully predicted vocational and independent living outcomes with neuropsychologically disabled individuals receiving rehabilitation services. In addition, preliminary validation studies suggest that the abbreviated MDS is useful for clinical neuropsychological diagnosis. The present study represents part of an ongoing research project aimed at validating the expanded version of the MDS for diagnosis of neuropsychological dysfunction. Specifically, it was hypothesized that the expanded MDS would be able to accurately discriminate between brain-damaged and non-brain-damaged individuals. Accurate diagnosis facilitates rehabilitation efforts for individuals with neuropsychological disabilities and the data profile provided by the expanded version of the MDS can consequently form the basis from which more complete individual treatment and rehabilitation plans can be conceptualized.

MDS profiles of brain-damaged individuals (N = 137) were compared with those of normal controls (N = 64). Results of discriminant function analyses supported the hypothesis that the MDS successfully differentiates between the two groups (83.1% correct classification using seven MDS global factor variables). Stepwise analysis indicated significant contributions from measures of intelligence and motor behavior as the

most important discriminating variables. Evaluation of a more comprehensive model revealed additional contributions from subtests added to the original MDS battery assessing verbal learning and active information processing. Results also supported a relatively high contribution from sensory motor integration functions. Surprisingly, these MDS variables contributed more significantly to group separation than did traditional measures such as the Trail Making Test (Parts A and B) and Booklet Category Test from the Halstead-Reitan Neuropsychological Test Battery.

While these results are promising regarding the diagnostic utility of the expanded MDS, further research evaluating the contribution of specific emotional and behavioral measures included in this battery is necessary to determine the validity of the entire system. Additional predictive validation studies will also be necessary to evaluate the effectiveness of the extended MDS as a rehabilitation treatment planning tool.

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CHAPTER 1

INTRODUCTION

Neuropsychology originated from the larger branches of clinical psychology and neurology with the specific focus on the study of brain-behavior relationships. It evolved primarily in the 1940's as a separate discipline. In contrast to the traditional psychotherapeutic and assessment roles of clinical psychologists, neuropsychologists assess changes in behavior following known or presumed injury or disease, and relate these changes to specific regions or systems of the brain responsible for their occurrence. In other words, the emphasis is on defining underlying anatomical and physiological explanations of behavior. This emphasis on relating behavioral changes to different areas or systems of the brain grew partially in response to a need for accurate differential diagnosis in cases where neurological dysfunction was indicated in contrast to purely psychiatric disturbance (Golden, 1983; Lezak, 1983). While diagnosis is still a priority, the field of neuropsychology is expanding to also incorporate treatment recommendations, similar to the goals of assessment in clinical psychology. From a neuropsychological perspective, the assessment of the organic basis of behavior facilitates diagnosis, which allows neuropsychologists to determine the most appropriate individualized treatment or rehabilitation approach (Gilandas, Touyz, Beumont, & Greenburg, 1984).

Historically, the study of brain-behavior relationships has primarily involved the observation of changes in function following known brain injury or disease. Based on these observations, neuropsychologists have made inferences regarding the relationship between the functional and structural integrity of underlying brain systems and the subsequent behavioral output. In addition, as clinicians, neuropsychologists must try to identify components of behavior which indeed imply cerebral impairment versus alternative explanations. For example, symptoms of depression could be interpreted as either a normal emotional reaction to a medical diagnosis or as a direct consequence of physiological alterations in limbic functioning associated with disease or injury to the central nervous system (Heilman & Valenstein, 1979). Observations of functional behavior generally take place through a formal neuropsychological assessment with the specific focus of determining physiological explanations of behavior.

The field of neuropsychology continues to grow as research and development of diagnostic techniques and theories improve. Landmark studies utilizing regional cerebral blood flow to localize brain functions contributed significantly to the knowledge upon which neuropsychologists base their interpretations (Lassen, Ingvar, & Skinhoj, 1978). Furthermore, with the more recently evolving radiologic technology including the development of neuroimaging techniques, such as computerized tomography (CT) and magnetic resonance imaging (MRI), the focus in neuropsychology of determining the presence, absence, or localization of cerebral dysfunction has been enhanced. Today the information obtained from neurologists often provides an initial diagnostic focus from which the neuropsychologist elaborates an individualized picture of a person's brain

functioning. Neuropsychologists utilize this data in addition to the history, behavioral observations, and results from the neuropsychological evaluation (Gilandas et al., 1984; Golden, 1983; Schreiber, Goldman, Kleinman, Goldfader, & Snow, 1976). The integration of medical, radiological, and neurobehavioral data thus permits the neuropsychologist to determine an individual's residual functional strengths and limitations in an effort to develop appropriate treatment and rehabilitation plans. In contrast to the past emphasis on diagnosis only, there is a growing demand for empirically validated treatments for neuropsychologically disabled individuals (Rourke, 1991). This need has increased as more people are surviving traumatic brain injuries today than in the past (Dial, Chan, Tunick, Gray, & Marme, 1991). Therefore, theory-driven, psychometrically sound assessment techniques are not only essential to diagnosis, but also for providing appropriate recommendations for subsequent treatment and rehabilitation.

<div align="center">Neuropsychological Assessment</div>

Neuropsychological assessment initially developed in response to a need for accurate diagnosis and subsequent rehabilitation of brain damaged individuals. Many neuropsychological laboratories came into existence following World War II to address these issues (Kolb & Whishaw, 1990; Lynch, 1983). Prior to the development of formal neuropsychological assessment, many practical problems arose in clinical practice. For example, there were growing needs for clarification of neurological diagnoses and for the development of noninvasive instruments that could assist in assessing change over time following a brain injury, or neurosurgery. In addition, clinical psychologists needed differential diagnoses for individuals with suspected underlying neurological disorders

which may be impacting the person's emotional and functional behavior (Lezak, 1983). Over time, neuropsychological assessment also became useful in the early diagnosis of degenerative diseases, certain types of tumors, and in cases where other medical conditions, such as cardiovascular disease, affect neuropsychological functioning (Ariel & Strider, 1983; Incagnoli, 1986).

Today, the three main purposes of neuropsychological assessment include diagnosis, treatment planning, and research (Kolb & Whishaw, 1990; Lezak, 1983). Concerning diagnosis, neuropsychological assessment has traditionally been used to establish the presence or absence of brain damage. In addition, localizing brain damage is often the purpose of a neuropsychological evaluation (Kolb & Whishaw, 1990). Although the field of neuropsychology appears to be moving toward a more treatment-oriented approach, there is a strong argument to continue focusing on diagnosis including detection of brain damage and localization (Kane, Goldstein, & Parsons, 1989). In addition, detecting subtle and/or progressive lesions, as well as distinguishing between neurological problems and psychiatric disorders often becomes the focus of diagnosis for neuropsychologists. These clinicians are also asked on many occasions to provide prognostic information about their clients. In some cases, answers to these types of questions may require several assessments over a period of time following injury to facilitate accurate prognosis regarding a return of functioning. Finally, there are occasions in which behavioral changes occur suggesting brain injury even though neurological exams may not have detected any structural damage. For example, individuals who have sustained postconcussive disorders often complain of attentional difficulties, memory

problems, and/or emotional lability, although existing radiologic tests may not detect any obvious structural abnormality. Other diagnostic applications include identifying individuals with early degenerative diseases or cases involving specific learning disabilities (Knights & Bakker, 1976; Kolb & Whishaw, 1990). Therefore, neuropsychological assessment can often detect and characterize subtle impairment which may impact functional behavior that is otherwise left medically undetermined (Kolb & Whishaw, 1990; Lezak, 1983). This ability to detect and individually characterize functional impairments in the absence of positive radiologic evidence is a unique feature of neuropsychological evaluation in addition to its ability to identify spared functional capabilities. In essence, while radiologic and/or neurologic findings are often necessary, the contribution of neuropsychological assessment is far from redundant (Lynch, 1983; Schreiber, et al., 1976).

The second major purpose of neuropsychological assessment is treatment planning, which often includes such issues as self-care and return to work. Administration of a neuropsychological test battery is useful in this regard since it leads to the development of rehabilitation efforts following the determination of an individual's level of functioning in multiple areas (cognition, language, memory, perception, etc.). A conceptualization of the individual's relative strengths and weaknesses across a variety of higher cortical functions enables the rehabilitation team to develop individualized treatment strategies.

Neuropsychological assessment is also utilized to enhance the research in understanding brain-behavior relationships. More recently, research in neuropsychology has extended beyond the simple correlation of test profiles and brain integrity to focus on

the study of the relationship between brain functioning and subsequent adaptive or functional behavior as manifested in community environments. Furthermore, neuropsychologists have also continued to focus their efforts on studying normal brain functioning to determine which regions or systems are important for the mediation of different types of behavior (Lezak, 1983).

Neuropsychological impairment is multidimensional, thus it requires adequate assessment of all types of functional behavior which will assist in revealing underlying pathology. A variety of higher cortical functions needs to be assessed, including: cognitive abilities; memory; problem solving strategies; judgment and planning; sensory integration abilities; and perceptual-motor skills. The neuropsychological evaluation also typically incorporates traditional clinical information regarding emotional-personality variables as well. Finally, a careful clinical interview and general behavioral observations are a necessary part of the neuropsychological evaluation to recognize the role of historical events and the present behavioral manifestations which play a part in the clinical picture and further clarify diagnoses (Dial, 1983; Golden, 1983; Incagnoli, 1986; Lezak, 1983).

Lezak (1983) suggests that it is useful to conceptualize the purpose of neuropsychological assessment as an evaluation of three systems including intellect, emotionality, and behavioral control. These three systems impact all functional behavior and are therefore essential components to assess when evaluating brain functioning. Intellectual functions include expressive and receptive language, memory, learning, and cognition, which are collectively referred to as higher level problem solving abilities. Personality variables and level of emotional coping are also important for an individual's

general functional capabilities. Following brain injury, there are typically some changes in personality and/or emotional coping that are common behavioral reflections of specifically injured anatomical sites. Finally, behavioral control refers to the ability to act or inhibit certain behaviors. This system of control interacts with the other two systems of intellectual ability and emotionality illustrated by Lezak (1983). This suggests that impairment of the control system will necessarily affect the other two systems.

While the three systems described by Lezak (1983) are generally assessed in some way or another during an evaluation, there are no formal rules in neuropsychological assessment regarding which specific tests are the most useful. Depending upon theoretical orientation, some neuropsychologists use a fixed battery while others employ a flexible approach. A third group use a combination approach since there are advantages to using either a fixed or flexible battery (Golden, 1983; Osmon, 1983). A fixed approach, also referred to as the battery or standardized approach, is one in which the neuropsychologist uses the same battery of tests for each person regardless of the presenting problem (Dial et al., 1991; Kane, 1991). Advantages for using a fixed approach include comprehensiveness and amenability to standardization (Kane, 1991). In addition, it has been suggested that the probability of a valid diagnosis may be increased by using a fixed battery since its thoroughness may make it more likely that otherwise unnoticeable deficits will be detected (Gilandas et al., 1984). Finally, the fixed approach is also more useful for research purposes since the same tests are administered to each individual. On the other hand, it has been suggested that fixed batteries often lack a guiding theory behind their ability to adequately explain brain-behavior relationships. Fixed batteries are also generally more

time consuming, and thus less cost-efficient (Gilandas et al., 1984). Finally, they lack the sensitivity to detect subtle reasons for observed deficits since these deficits are not further explored once they are revealed (Osmon, 1983).

A neuropsychologist using a flexible approach, also referred to as a process or clinical approach, utilizes different tests or procedures depending upon the person's presenting problems and the specific referral questions (Dial et al., 1991; Kane, 1991). The flexible approach is desirable for those wanting a more in-depth, individualized explanation of the person's deficits and is therefore considered to be more qualitative in nature (Dial & Chan, manuscript in preparation; Kane, 1991). This approach allows for a more thorough examination of each individual's particular presenting complaints and may be more successful in many cases at detecting the relationship between the behavior the individual is displaying and the underlying brain pathology. However, one of the major disadvantages to the flexible approach is that it requires considerable experience and a firm theoretical orientation regarding the functioning of the brain to appropriately select, administer, and interpret assessment techniques (Gilandas et al., 1984). Furthermore, the examiner must have sufficient knowledge to be aware of normal variance in behavior and how this differs from changes in behavior due to organic causes (Dial & Chan, manuscript in preparation).

While there still remains disagreement about whether the fixed approach or flexible approach is a better method for diagnostic purposes and subsequent treatment planning, there are some general guidelines regarding which characteristics comprise a useful battery of tests (Kolb & Whishaw, 1990; Osmon, 1983). The psychometric properties of the battery are of utmost importance. For example, tests should be administered with

standardized procedures and be scored in a standardized manner. Neuropsychological test batteries should also be reliable and valid measures in order for them to be useful. It is obviously imperative that neuropsychological instruments are also sensitive to changes in brain functioning such that differences in performance can be related to such changes. Performance on neuropsychological test instruments should also relate to appropriate treatment recommendations including rehabilitation efforts and/or education. Unfortunately, most batteries in existence do not demonstrate this relationship (Dial, 1983; Dial & Chan, manuscript in preparation).

Another indicator of a useful neuropsychological test battery is that it assesses a wide variety of functions. This thoroughness is necessary since brain injury can simultaneously affect several different functional behaviors. This point can be illustrated by results of a study that investigated the utility of neuropsychological test batteries versus the use of a single intelligence test in the detection of brain dysfunction. In this study, discriminant analysis suggested that the correct classification for the most frequently used intelligence test (Wechsler Adult Intelligence Scale) was lower than for the neuropsychological test batteries (Halstead-Reitan Neuropsychological Test Battery and the Luria-Nebraska Neuropsychological Battery) (Goldstein & Shelly, 1984). Thus, although intelligence tests are often included as an integral component of neuropsychological test batteries, they lack sufficient sensitivity by themselves to appropriately diagnose brain dysfunction. On the other hand, while there is evidence suggesting that the WAIS has been useful in lateralizing brain lesions, it has been suggested that these differing results may have to do with the population being sampled

(Parsons, Vega, & Burn, 1969; Uzzell, Zimmerman, Dolinskas, & Obrist, 1979). In a population of individuals with more severe or diffuse damage, individual assessment measures need not be as sensitive in order to determine cerebral impairment. Likewise, individuals with more localized damage, or less severe impairment may perform within normal limits on several tests that are supposedly sensitive to neuropsychological impairment. In order to adequately assess neuropsychological functioning, a comprehensive approach including a variety of test procedures is needed; this process often requires approximately six hours of individual test administration (Kolb & Whishaw, 1990).

Other important aspects of a useful neuropsychological test battery are ease of administration and cost-effectiveness. If tests are easy to administer, there is less room for error regarding standardized procedure. Cost-effectiveness in this context refers to the actual cost in time of administering tests. If tests take too long to administer, neuropsychologists may choose to not use them and thus essential information may be missed in the evaluation. Administration time may further affect the validity of certain test results; since many neuropsychologically impaired individuals tend to fatigue more quickly, it is likely that the examiner will not obtain optimal performance from brain-damaged individuals if they administer excessively long test batteries. It is essential to allow for breaks as necessary and it may be useful to split the testing session over several days. Otherwise, the interpretation of test results will obviously be affected by this factor of fatigue (Kolb & Whishaw, 1990).

Finally, the adaptability and portability of tests should also be considered. For example, neuropsychologists must often go outside of their offices to administer tests in rehabilitation facilities or at bedside in a hospital. Ideally, the tests themselves should be adaptable to such environmental constraints. In addition, neuropsychological test batteries should remain flexible. Research serves the purpose of updating tests and norms which suggests that neuropsychologists must be prepared to change their typical batteries when improvements are made (Kolb & Whishaw, 1990; Osmon, 1983).

<div align="center">Neuropsychological Profiles</div>

Regardless of the approach utilized, there are often certain common indicators of cerebral dysfunction which appear on neuropsychological test profiles (Kolb & Whishaw, 1990; Lezak, 1983). For example, when interpreting test results, neuropsychologists look for intraindividual variation, such as intratest or intertest scatter, which may signal organicity. Certain so-called pathognomonic signs, by definition, alert the clinician to the probability of cerebral dysfunction. Furthermore, many subtests within neuropsychological test batteries have been found to be particularly sensitive to brain impairment and as such are often used as initial screening variables to generate hypotheses about an individual's level of neuropsychological functioning.

As a general rule, functional deficits usually appear in a certain patterns corresponding to the area and/or systems of the brain that are injured. In addition, similar patterns of results among different tests within the battery often suggest injury corresponding to the areas or systems that have been damaged. For example, there is usually a different pattern observed between focal and diffuse damage. Focal lesions are

caused by specific anomalies such as tumors, aneurysms, cerebral vascular accidents (stroke), and in penetrating head injuries often caused by gunshot wounds. These lesions generally affect a specific area of the brain, although it is not uncommon to observe some diffuse damage as well. Patterns of accompanying deficits in focal lesions are therefore rather specific, while other functional behavior remains relatively intact. However, it is also important to recognize that with sudden onset symptoms, focal lesions may mimic diffuse damage. This suggests an interaction among many variables that must be carefully considered when interpreting a case (Lezak, 1983).

Diffuse damage refers to widespread involvement of the brain that is characterized by either global deterioration or several focal lesions (Gilandas et al., 1984; Lezak, 1983). Certain degenerative and metabolic diseases, such as Alzheimer's disease often cause diffuse damage. In addition, diffuse damage is often observed in high velocity head-in-motion injuries from motor vehicle accidents. Often in these head-in-motion injuries, the individual experiences a lesion to the basilar frontal lobes, referred to as the coup lesion, with concomitant damage also observed in the medial temporal areas or in locations on the opposite side of the brain. This damage observed to the areas of the brain opposite the point of impact is referred to as a contrecoup lesion and is due to energy dynamics of force transmitted through the brain mass (Gilandas et al., 1984; Filley, 1995; Lezak, 1983; Richardson, 1990). This force may also result in multiple microscopic contusions that collectively produce diffuse brain injury. Due to its widespread involvement, this diffuse damage affects a broader range of functional behavior, as would be expected.

Lateralization of lesions also results in certain patterns on neuropsychological test profiles. Lateralization refers to involvement of either the left or right cerebral hemisphere. It has been well documented in the literature that, generally speaking, left hemispheric damage affects verbal behavior while lesions of the right hemisphere impact visuo-spatial abilities (Geschwind, 1979; Kimura, 1978; Lezak, 1983; Parsons, et al., 1969). However, it is also important to mention the contribution of the right hemisphere to language functions to emphasize the fact that the two hemispheres do not operate independently (Gazzaniga, 1967; Lassen, et al., 1978). It appears that this observed pattern of hemispheric specialization is not impacted by other variables such as age, education, emotional disturbance or even localization, acuteness, and severity of the brain injury (Parsons et al., 1969). Although congenital or very early lateralized lesions may have a significant impact on cerebral organization and consequently alter the common or expected neuropsychological patterns. Subcortical involvement also impacts the particular type of impairment that the individual will exhibit behaviorally.

Chronicity is also an important factor to consider when examining a neuropsychological profile. When interpreting a profile from an individual with an acute (recent) injury, certain expectations are maintained regarding level of return of functioning. In contrast, when the person is beyond approximately two years post-injury (chronic), it is likely that the level of functioning has reached a plateau. However, there is an interaction among chronicity, extent of damage and etiology of the lesion which will ultimately determine the outcome (Lezak, 1983). Therefore, different levels of

interpretation can be made depending upon the time since the insult to the brain and the interactions this has with other variables of the injury.

Furthermore, some types of brain damage are considered static in nature, meaning the condition is not expected to change, while others are progressive in nature suggesting a further deterioration of functioning over time. Certain tests are relatively sensitive to more acute and/or quickly progressing injuries versus those that are considered relatively static in nature. These tests are particularly useful in the detection of certain types of fast-growing tumors or degenerative diseases (Reitan & Wolfson, 1993).

An individual's age at the onset of the brain injury/disease impacts the impairment and subsequent recovery. In general, it appears that the impact of brain damage is greater as age increases, although it is also important to consider other factors including severity of the lesion (Lezak, 1983). Gender also impacts neuropsychological profiles. Several studies have shown that females typically outperform males on certain verbal tasks while males tend to do better than females on particular tests of visuospatial functions and that the structural and functional organization of the brain differs between the sexes (Kimura, 1978; Lezak, 1983).

The issue of substance abuse must be considered when examining a neuropsychological profile since there is evidence suggesting that chronic alcohol and drug use could indeed affect cognitive functioning (Fals-Stewart, Schafer, Lucente, Rustine, et al., 1994; Fals-Stewart, Shanahan, & Brown, 1995; Mathew & Wilson, 1991; Rosseli & Ardila, 1996; Tarter, Moss, Arria, & Van-Thiel, 1990; Weinreib & O'Brien, 1993; Weinstein & Martin, 1995; Weinstein & Schaffer, 1993). A review of the literature

conducted by Weinstein and Martin (1995) revealed that the relationship between traumatic brain injury and alcohol abuse can be conceptualized as biopsychosocial in nature. This is because alcohol abuse often results in traumatic brain injury (e.g., driving while intoxicated). It is estimated that approximately fifty percent of the total number of acquired brain injuries are alcohol-related (Miller, 1989). Conversely, the direct effects of alcohol are thought to predispose certain neurochemical processes resulting in brain dysfunction. More specifically, there is evidence suggesting that the prefrontal/frontal cortex is impaired in chronic substance abusers (Weinstein & Schaffer, 1993). It appears that the effects of substance abuse and head injuries are interactive, thus both affecting neuropsychological functioning and also often resulting in dual diagnoses of alcohol dependence and organic brain disorder (Solomon & Malloy, 1992; Weinstein & Martin, 1995). However, while the effects of substance abuse tend to impact certain neuropsychological functions, such as verbal and non-verbal short-term memory and abstraction abilities, there is also evidence suggesting that abuse is not necessarily associated with many other indicators of neuropsychological impairment (Campbell & Hodgins, 1993; Rosseli & Ardila, 1996).

Finally, premorbid functioning is another factor that is important to consider when interpreting results. Following brain injury, individuals with higher levels of premorbid functioning tend to adjust more efficiently, and to a greater degree than those with lower levels of premorbid functioning. In addition, education is positively correlated with neuropsychological test performance, as well as the degree of improvement following brain injury (Lezak, 1983). Certain patterns are often expected on neuropsychological test

profiles regarding the aforementioned factors, but if premorbid functioning is not taken into consideration, inappropriate conclusions could be drawn. The difficulty in neuropsychological interpretation lies in individual differences that may be responsible for one's performance on a neuropsychological test battery (Kolb & Whishaw, 1990). In general, it is important to consider all of these factors when interpreting neuropsychological profiles to assist accurate diagnosis.

Neuropsychological Test Batteries

Although many neuropsychologists choose tests from among many different batteries, there are some benefits to using a well-established, standardized battery. For example, established batteries are more likely to have well-documented psychometric properties. Since the purpose of the present study is to study the validity of the expanded McCarron-Dial System (MDS), it is important to examine this battery in the context of two of the most commonly used neuropsychological assessment batteries: the Halstead-Reitan Neuropsychological Test Battery (HRNTB) and the Luria-Nebraska Neuropsychological Battery (LNNB). A review of these batteries including their psychometric properties will be provided in the following sections in addition to an overview of the MDS.

Halstead-Reitan Neuropsychological Test Battery. Ward Halstead based his assessment techniques upon his own investigations of brain injured patients at the University of Chicago. He opened his neuropsychology test laboratory in 1935 (Gilandas et al., 1984; Parsons, 1986; Russell, Neuringer & Goldstein, 1970). Halstead's main goal was to develop a series of tests that would accurately discriminate brain-injured from non-

brain-injured adults. He developed his battery of tests in 1947 and was particularly

interested in assessing what he termed "biological intelligence." Halstead believed that

biological intelligence was different than psychometric intelligence, or what standardized

intelligence tests are thought to measure. He suggested that biological intelligence was

more comprehensive and that it reflected an individual's overall ability to adapt to and

cope with the environment (Russell, et al., 1970). He also believed that biological

intelligence better reflected the overall functioning of the central nervous system as

opposed to psychometric intelligence which was thought to reflect educational training

(Parsons, 1986). Halstead viewed the frontal lobes as the most important underlying brain

structures mediating biological intelligence. Therefore, much of his work focused on

attempting to develop assessment instruments sensitive to frontal lobe functioning.

Ralph Reitan, Halstead's student, established his own laboratory in 1951 at the

Indiana University Medical Centre (Gilandas et al., 1984; Parsons, 1986; Reitan &

Wolfson, 1993). Reitan combined the theoretical tenets of Halstead with important

psychometric properties resulting in a modified and expanded battery of tests that were

originally developed by Halstead. Reitan was not as focused on Halstead's concept of

assessing biological intelligence as he was on examining the particular relationships

between behavior and various aspects of brain damage including the localization of lesions

(Russell, et al., 1970). Reitan's revision of Halstead's original battery is now known as the

Halstead-Reitan Neuropsychological Test Battery (HRNTB). The HRNTB is now the

most widely used neuropsychological test battery in the United States and Canada

(Parsons, 1986). Reitan has since also validated two neuropsychological test batteries for

children; one for younger children and one for older children/adolescents (Reitan & Wolfson, 1993).

Halstead's theory of brain functioning suggests that the first level of central processing involves alertness and attention in addition to the registration and comparison of incoming information with that which is stored in memory. Reitan and Wolfson (1993) suggest that the next step involves the lateralized functions of the two cerebral hemispheres such that verbal information is processed in the left hemisphere and visuo-spatial information is processed in the right hemisphere. The highest level of central processing is mediated throughout the cerebral cortex and is represented by abstraction, concept formation, reasoning, and logical analysis. Their theory suggests that a breakdown of neuropsychological functioning can occur at any level. This underscores the need to assess all levels of functioning via neuropsychological assessment. The HRNTB was developed to measure each of these important behavioral dimensions.

Important components of the HRNTB include: (a) comprehensiveness, (b) ability to yield different profiles regarding brain-behavior relationships, (c) amenability to valid neuropsychological interpretations, and (d) a delicate balance between standardization and flexibility (Gilandas et al., 1984). Reitan and Wolfson (1993) emphasize the importance of measuring a variety of psychological functions represented by the brain in such a way that individualized interpretation is meaningful. Furthermore, they also underscore the importance of developing psychometric properties through formal research for the entire battery, as well as, the individual subtests to assure their sensitivity to cerebral dysfunction (Reitan & Wolfson, 1993). Reitan incorporated four methods of inference which are

addressed by different tests within the battery. These include: (a) level of performance, an index which compares an individual's performance to a normative group; (b) pathognomonic signs, or occurrence of specific deficits; (c) patterns and relationships among test scores; and (d) lateralization. These methods of inference serve to identify and localize cerebral dysfunction, which is the foremost purpose of the HRNTB.

Reitan and Wolfson (1993) report that the HRNTB is the most thoroughly studied neuropsychological test battery. The reliability and validity of the HRNTB has been well documented in the literature suggesting accurate classification of brain-injured versus non-brain-injured individuals utilizing a variety of statistical techniques (Filskov & Boll, 1981). Results of validation studies utilizing discriminant functional analysis suggest "hit rates" between 70 and 94% (Gilandas et al., 1984). While these figures are impressive regarding the battery's utility as a diagnostic tool, there has been little research to date regarding the validity of the HRNTB in predicting vocational rehabilitation outcomes (Dial et al., 1991). Another limitation of the battery described in the literature is the lack of a relationship between Reitan's theory regarding brain functioning and the actual development of the tests that are included in the battery. In fact, many of the tests were developed by other authors for a variety of different purposes and were incorporated into the Halstead-Reitan battery on an empirical rather than theoretical basis (Kolb & Whishaw, 1990; Tarter & Edwards, 1986). Other limitations and criticisms of the HRNTB include: the lack of uniform age and educational norms; insensitivity of certain tests; and the failure to include adequate measures of memory functions (Parsons, 1986). In general, despite a variety of merits, the battery does not entirely meet the guidelines of thoroughness described by

Kolb and Whishaw (1990). These authors suggest that a thorough revision of the HRNTB

is needed to correct its shortcomings.

    <u>Luria-Nebraska Neuropsychological Battery.</u> A.R. Luria developed his

neuropsychological test procedures based upon approximately 35 years of his personal

investigations of individuals with brain injuries in the Soviet Union (Kolb & Whishaw,

1990). According to Luria, the two basic principles that guide assessment of brain

dysfunction are localization of brain lesions and the analysis of behavior, which coincides

with brain functions. His functional systems theory is one of the most comprehensive

theories regarding brain functioning to date as he speculated on the unknown etiology of

complex behaviors (Luria, 1970). Luria's theory suggests that no specific brain region is

uniquely responsible for any given function, rather different regions work together to

produce behaviors. Conscious activity is a result of a complex composition of brain

activities, which Luria refers to as a functional system. Luria suggested that the brain

consists of three main functional units: the arousal unit, the sensory reception and

integration unit, and the programming unit (Luria, 1973). The arousal unit (Unit I) is

mediated by the reticular activating system, diencephalon, and the limbic system. Unit I is

responsible for regulating cortical tone, as well as waking and mental states. This includes

metabolic processes and the orienting reflex (Luria, 1973). Unit I is responsible for

filtering sensory input and is therefore essential for attention. The sensory reception and

integration unit (Unit II) comprises temporal, parietal, and occipital cortex. Luria (1973)

suggested that within this unit is a suborganization which is hierarchical; the primary,

secondary, and tertiary zones. The primary zone is responsible for detection of

somatosensory input. The secondary zone involves analysis, coding, and storage of information, while the tertiary zone is the junction at which different sensory sources are integrated. The programming unit (Unit III) is the highest level of human behavior located in the frontal lobes. This unit integrates the planning and evaluation of behavior as well as execution of motor output. Luria (1973) suggested that the three functional units interact producing voluntary behavior.

Luria preferred a flexible approach for his assessment techniques due to his theoretical orientation. Christensen (1979) systemized Luria's techniques and published several case studies using his methodology. A standardized version of Christensen's techniques with some modifications was introduced in 1981 by Golden and associates with the intent of preserving as much of Luria's process approach as possible (Golden, Hammeke, & Purisch, 1980). The Luria-Nebraska Neuropsychological Battery (LNNB) is a 269-item multidimensional battery developed to diagnose cognitive deficits and assist in planning for rehabilitation efforts. The battery was also developed in part to test the theoretical tenets regarding brain-behavior relationships upon which it is based. In addition to quantitative assessment, the LNNB is unique in that it also allows for a qualitative rating of behaviors which is considered useful in the process of generating hypotheses regarding underlying brain functioning (Golden & Maruish, 1986).

Many validation studies have been conducted with the LNNB suggesting that its classification accuracy between brain-damaged and non-brain-damaged controls is essentially equal to that of the HRNTB (Golden & Maruish, 1986). In fact, the initial validation study, which included the 30 most sensitive items out of the total 269, resulted

in a 100% accuracy rate between 50 brain-damaged and 50 non-brain-damaged controls

(Golden, et al., 1978). Many subsequent studies have also documented the validity of the

LNNB (Golden & Maruish, 1986). However, there is some disagreement in the literature

regarding the psychometric properties of the LNNB (Sears, Hirt, & Hall, 1984). For

example, Sears, Hirt, and Hall (1984) suggest that while the LNNB appears relatively

effective in distinguishing brain-damaged individuals from normal controls, it is not

particularly useful for detecting the lateralization of brain damage. On the other hand, a

study comparing the diagnostic accuracy of the HRNTB and the LNNB suggested that the

standardized LNNB appears promising (Kane, Sweet, Golden, Parsons, & Moses, 1981).

Yet another study comparing the effectiveness of the HRNTB, LNNB, and the Wechsler

Adult Intelligence Scale (WAIS) for diagnosis of neuropsychological impairment

suggested that the discriminative validities of the HRNTB and the LNNB were essentially

equal and both were superior to the WAIS. Therefore, although there remains some

controversy regarding the LNNB, many studies concur that it is useful at least in

discriminating brain-damaged from non-impaired controls (Golden & Maruish, 1986).

Similar to the HRNTB, the LNNB lacks sufficient research regarding its applicability to

the formulation of appropriate treatment recommendations (Dial & Chan, manuscript in

preparation). This is considered a serious limitation of both test batteries since the field of

neuropsychology is rapidly moving toward including treatment recommendations.

McCarron-Dial System. The McCarron-Dial System (MDS) has been used in the

fields of rehabilitation, neuropsychology, and education for over twenty years as a

planning and diagnostic battery (Chan & Dial, 1987; Dial, Freemon, McCarron, &

Swearingen, 1979; Dial & Swearingen, 1976; Patton, 1981). In contrast to the HRNTB

and the LNNB, the MDS was originally developed to assess vocational and independent

living potential among neuropsychologically disabled adults (Chan & Dial, 1987; Chan,

Parker, Dial, Lam, & Carter, 1986). The MDS has been used to evaluate various types of

neuropsychological impairment including acquired brain injury, mental retardation,

cerebral palsy, and learning disabilities (Dial & Henke, 1978; McCarron & Dial, 1976;

McCarron & Ludlow, 1981; Texas Rehabilitation Commission, 1979). This system was

introduced to the rehabilitation field in 1973 and has been used to extensively assess work

potential in neuropsychologically disabled adults (Chan & Dial, 1987; Chan, et al., 1986).

Luria's functional systems theory (in concert with some traditional views of brain

functioning) guided the development of the MDS (Dial, 1983). The traditional model of

brain functioning emphasizes the lateralized functions of the two cerebral hemispheres in

addition to cerebral dominance for certain functional behaviors. Luria's model emphasizes

the integration of several systems within the brain that are responsible for behavior.

The MDS has been proven successful at predicting work and independent living

outcomes with a neuropsychologically disabled population (Bihm & McCarron, 1988;

Blackwell, Dial, Chan, McCullum, 1985; Chan, et al., 1986; Chan & Dial, 1987; Dean,

Bond, & Lewis, 1991; Dial, Chan, Parker, Carter, & Pomeroy, 1988; Dial, Chan, Tunick,

Gray, & Marme, 1991; Fortune & Elridge, 1982; McCarron & Dial, 1972; McCarron &

Ludlow, 1981). The MDS has only recently been utilized as a neuropsychologically based

diagnostic test battery and the initial research is promising. For example, Dial (1983)

compared neuropsychologically disabled clients to psychiatric controls to assess the

validity of the MDS as a neuropsychological battery. The results of this study revealed that 97% of the brain-damaged group and 71% of the controls were accurately classified using discriminant function analysis. Other studies provide evidence of the system's validity as a neuropsychological test battery. Chan and Dial (1987) obtained 89% correct classification rates when comparing 92 brain-damaged rehabilitation clients to 39 non-brain-damaged, psychiatric controls. Dial, Chan, and Norton (1990) compared 92 brain-damaged individuals with 30 controls. Results of the discriminant analysis indicated 93% classification accuracy. Furthermore, a 74% accuracy rate was obtained in the classification of lateralized and diffuse brain-damaged groups.

The MDS is based upon a rational model of evaluation comprised of data gathering, hypothesis formulation, and finally, hypothesis testing. Data gathering is conducted through interviewing, behavioral observations, and standardized testing. The formulation of hypotheses occurs when the data are integrated. In the final stage, hypothesis testing, the recommendations from the evaluation are followed and results are then analyzed to assess the effectiveness (McCarron & Dial, 1986).

The MDS expanded incorporates tests from external sources, such as the Wechsler Adult Intelligence Scale - Revised (WAIS-R; Wechsler, 1981), the Booklet Category Test and Trailmaking Parts A and B from the Halstead-Reitan Neuropsychological Test Battery (Reitan & Wolfson, 1993), in addition to those developed by the MDS authors. While the MDS was originally conceptualized as comprising five factors, factor analysis suggests that it is actually composed of three factors: Verbal-Spatial-Cognitive (VSC) , Sensory-Motor (SM), and Emotional-Coping (EC) (Chan, et al., 1986). In the expanded version of

the MDS, the VSC factor is made up of the following tests: WAIS-R (Wechsler, 1981); Wide Range Achievement Test (WRAT-3; Wilkinson, 1993); Booklet Category Test (Reitan & Wolfson, 1993); Trail Making, Parts A and B (Reitan & Wolfson, 1993); Letter Number Learning, Auditory Analysis, and Language Comprehension and Memory from the verbal portion of the Cognitive Test for the Blind (Dial, Mezger, Gray, Chan, & Massey, 1991), and the Spatial Relations (SR) subtest from the Perceptual Memory Test (PMT) (McCarron, 1984). Together these tests measure an individual's ability to process both language and nonverbal information, in addition to the assessment of learning ability. Higher level cognitive functions such as an individual's ability to reason, and memory functions are all part of this factor. This factor is also important for the assessment of an individual's future learning potential in different settings, which is essential for educational and vocational planning. Tests that were added to the MDS from previous versions are all within the VSC factor and include: Trail Making Parts A and B, Booklet Category Test, Auditory Analysis, Language Comprehension and Memory, Letter Number Learning, and Spatial Relations.

The SM factor is made up of the Bender Visual Motor Gestalt Test (BVMGT; Bender, 1938), regular and memory presentations; the Haptic Visual Discrimination Test (HVDT; McCarron & Dial, 1979); and the McCarron Assessment of Neuromuscular Development (MAND; McCarron, 1982). This factor assesses an individual's ability to incorporate sensory information through different modalities in an adaptive manner. The sensory and motor systems are both essential for voluntary movement (McCarron & Dial, 1986).

Finally, the EC factor is composed of the Minnesota Multiphasic Personality Inventory (MMPI; Hathaway & McKinley, 1967); Rotter Incomplete Sentence Blanks (RISB; Rotter & Rafferty, 1950); and the House-Tree-Person Drawings (HTP; Buck & Jolles, 1966). In addition, the Street Survival Skills Questionnaire (SSSQ; Linkenhoker & McCarron, 1979), Survey of Functional Adaptive Behaviors (SFAB; Dial, Mezger, Massey, Carter, & McCarron, 1986) and/or the Observational Emotional Inventory (OEI; McCarron & Dial, 1986) are often utilized as assessment tools for emotional coping. This factor is essential since many individuals with neuropsychological dysfunction exhibit deficits of one kind or another in this area. Often individuals with brain damage have difficulties with interpreting social cues, or exhibit emotional lability, for example. The EC factor will be excluded from the present study as control subjects will not be administered these tests.

The Research Problem

While the MDS was originally developed to predict vocational outcomes in rehabilitation clients, there is also promising evidence regarding its utility for the diagnosis of neuropsychological dysfunction. However, as the MDS continues to expand, additional research is necessary to establish its validity in the field of neuropsychology. In contrast to the focus on practical and functional outcomes in the rehabilitation field, diagnosis and treatment planning are generally regarded as the purposes in clinical neuropsychological assessment. The utility of the expanded MDS will therefore be extended if it is proven clinically valid for this latter purpose; e.g., the MDS could provide both an accurate

diagnosis and clarification of specific needs from which an individualized rehabilitation plan can be formulated.

The purpose of the present study is to extend the validation research of the MDS regarding its clinical use as a neuropsychological test battery. Preliminary studies have not compared neuropsychologically disabled individuals to a non-brain-damaged control group using the expanded MDS. Several subtests have been added to the Verbal-Spatial-Cognitive Factor with the intent of improving diagnostic sensitivity of this factor as well as extending the functional assessment of cognitive abilities. Therefore, additional research of the battery is needed to investigate the contribution that these additions may have to the system's diagnostic validity. Comparison studies assessing classification rates between brain-damaged and non-brain-damaged controls is a common technique following neuropsychological test battery construction and thus would appear an appropriate, necessary method to establish the validity of the MDS. To answer questions regarding the system's validity, the following hypotheses were formulated: (a) the expanded MDS will accurately discriminate between brain-damaged and non-brain-damaged controls; (b) the expanded MDS will achieve correct classification rates in excess of the abbreviated versions; and that (c) the expanded MDS will demonstrate classification rates comparable to the HRNTB and the LNNB.

Dependent Variables (Brain-Damaged vs. Non-Brain-Damaged)

In discriminant function analysis a prediction equation is formed based upon independent variables which are used to classify subjects into groups. Therefore, independent variables are plotted against the grouping variable. As discriminant analysis

will be utilized for the major analyses of the present study, the dependent variables will be

the grouping variables: brain-damaged and non-brain-damaged.

Independent Variables (MDS factors and subtests)

In the present study, the independent variables are the MDS Verbal-Spatial-

Cognitive and Sensory-Motor measures. The following are specific Verbal-Spatial-

Cognitive variables utilized in the analyses for the present study:

1. WAIS Full Scale IQ (FSIQ)

2. WAIS Verbal IQ (VIQ)

3. WAIS Performance IQ (PIQ)

4. Algorithm 7 (ALGO7) -- WAIS Comprehension scaled score (age-corrected)

   plus Picture Completion scaled score (age-corrected) divided by 2 minus

   Arithmetic scaled score (age-corrected) plus Digit Span scaled score (age-

   corrected) plus Digit Symbol scaled score (age-corrected) divided by 3 (>= 0)

   – Considered as a general brain damage indicator (Becker, 1975; Davis,

   DeWolfe, & Gustafson, 1972; Russell, 1979)

5. Booklet Category Test T-Score (BCTTSCORE)

6. Trail Making Part A T-Score (TRAILSAT)

7. Trail Making Part B T-Score (TRAILSBT)

8. Auditory Analysis scaled score (AA)

9. Language Comprehension and Memory scaled score (LCM)

10. Letter Number Learning scaled score (LNL)

11. Spatial Relations standard score (SR)

The following are specific Sensory-Motor variables used in the final analyses:

1. Bender Visual Motor Gestalt Test error score (BVMGTE)

2. Bender Visual Motor Gestalt Test memory score (BVMGTM)

3. Bender Visual Motor Gestalt Test localization score (BVMGTL)

4. Haptic Visual Discrimination Test Average standard score (HVDTAVG)

5. MAND Neuromuscular Development Index (NDI)

6. MAND Fine Motor Standard Score (FINE)

7. MAND Gross Motor Standard Score (GROSS)

CHAPTER 2

METHOD

Subjects

Archival data was collected from 137 clinical files to select anonymous cases with a medically documented history of acquired brain injury. Any injury acquired since birth (but not during the birth process) is considered to be an acquired injury. Acquired brain injuries can be caused by both external and internal sources. Therefore, closed or open head injury, non-congenital seizure disorder, cerebral vascular accident, anoxia, and systemic diseases such as multiple sclerosis or AIDS which effect the central nervous system and thus indicate cerebral impairment are considered to be acquired brain injuries (Savage & Wolcott, 1994). Table 1 (Appendix C) provides the breakdown of etiology and pathology of subjects in the present study. Subjects with only suspected brain damage due to unknown etiology, and those with congenital abnormalities were excluded. This includes individuals with primary diagnoses of learning disabilities, attention-deficit/hyperactivity disorder, and substance abuse, unless these subjects also have a history of acquired brain injury. Individuals with uncorrected peripheral sensory impairments were also excluded.

The subjects consisted of 91 males (66.4%) and 46 females (33.6%) between the ages of 16 and 75 (mean = 34.81, SD = 11.36). The subjects were distributed by race as follows: 91 (66.4%) Caucasian, 27 (19.7%) African American, 13 (9.5%) Hispanic, and 6 (4.4%) other. A premorbid right hand preference was reported by 82.5% of the subjects, while the remaining 17.5% were reportedly left-handed.

Control subjects consisted of 64 non-brain-damaged adults recruited from different departments from the University of North Texas in addition to other external organizations. An attempt was made to collect data from a representative sample of the general population specifically matching the brain-damaged group on demographic variables including age, education, and ethnicity. Control subjects that met inclusion criteria may also have been selected from anonymous clinical case files. Incentives were given to controls to encourage participation, including extra credit points for students and/or an opportunity to participate in a free workshop explaining the utility of the MDS. Control subjects met the following criteria: no history of congenital or acquired brain injury, learning disability, attention-deficit/hyperactivity disorder, substance abuse, or uncorrected sensory impairment.

Control subjects consisted of 22 (34.4%) males and 42 (65.6%) females between the ages of 18 and 59 (mean = 29.23, SD = 10.30). The race distribution was as follows: 54 (84.4%) Caucasian, 5 (7.8%) African American, 3 (4.7%) Hispanic, and 2 (3.1%) other. 81.3% of the group were reportedly right preferred, while 18.8% reported being left preferred.

<u>Apparatus</u>

The expanded MDS Verbal-Spatial-Cognitive and Sensory-Motor instruments were used in the present study. The following is a list of the specific tests, followed by a brief description of the ability that they are presumed to measure:

<u>Verbal-Spatial-Cognitive</u>:

Wechsler Adult Intelligence Scale - Revised (WAIS-R)

FSIQ – (analytical and synthetic intelligence)

Booklet Category Test (BCT) (abstract non-verbal learning)

Trail Making, Part A (cognitive motor functions)

Trail Making Part B (cognitive flexibility)

Auditory Analysis and Sound Repetition (AA) (phonemic analysis)

Language Comprehension and Memory (LCM) (verbal-contextual

memory)

Letter Number Learning (LNL) (rote verbal learning)

Spatial Relations (SR) (visuo-spatial memory and constructional praxis)

<u>Sensory-Motor</u>:

Bender Visual Motor Gestalt Test (BVMGT) (sensorimotor integration)

Haptic Visual Discrimination Test (HVDT) (tactile-visual integration)

McCarron Assessment of Neuromuscular Development (MAND) (overall

motor function)

<u>Verbal-Spatial-Cognitive</u>: Standardized tests were scored according to the requirements specified in their respective manuals. For example, the Full Scale I.Q.,

Verbal I.Q., and Performance I.Q.'s were computed for each subject on the WAIS-R (Wechsler, 1981). Age-corrected scaled scores were utilized for WAIS-R subtests.

The Booklet Category Test and Trail Making, Parts A and B are subtests from the Halstead-Reitan Neuropsychological Test Battery (Reitan & Wolfson, 1993). The Booklet Category Test assesses concept formation and nonverbal, abstract reasoning. Test-retest reliability for the original version of the test, the Halstead Category Test, is .91. Furthermore, the booklet version has been significantly correlated with the original version and has been cross-validated, yielding essentially the same results (McCarron & Dial, 1986). The gender, age, and education corrected T-score for the Booklet Category Test was the unit of measurement in the present study (Heaton, Grant, & Matthews, 1991). Trail Making Test, Part A assesses simple cognitive-motor speed and logical analysis. Trail Making, Part B measures cognitive flexibility in addition to cognitive-motor speed. Demographic corrected T-scores were recorded for Trail Making, Parts A and B in the present study. Both the Booklet Category Test and Trail Making, Part B are both considered particularly sensitive indicators of neuropsychological dysfunction (Reitan & Wolfson, 1993).

The Auditory Analysis, Language Comprehension and Memory, and Letter Number Learning subtests are part of the Verbal portion of the Cognitive Test for the Blind (Dial, et al., 1991). Studies of the Cognitive Test for the Blind suggest good test-retest reliability (r = .95) and concurrent validity to work level (r = .88) and living level (r = .79) (Dial et al., 1991). These subtests tap more fluid abilities than the verbal subtests from the WAIS-R and are therefore considered to be more sensitive to cognitive changes.

In the Auditory Analysis subtest, subjects are asked to repeat a series of word-like sounds, or nonsense words. This subtest assesses primary auditory detection, attention, and basic expressive language abilities (McCarron & Dial, 1986). For the Language Comprehension and Memory subtest, subjects listen to several short stories, then are asked questions regarding details of the stories. This subtest measures an individual's ability to discriminate relevant from irrelevant material presented orally. It assesses both receptive and expressive language (McCarron & Dial, 1986). Finally, the Letter Number Learning subtest requires subjects to repeat series of letter-number pairs (e.g., D-3, B-8). The subject is offered up to five trials to correctly learn the series. This subtest assesses rote learning ability, attention and concentration, as well as frustration tolerance. In the present study, subjects' raw scores for each of these subtests were converted to scaled scores (mean = 10, SD = 3). (Refer to Appendix B for an expanded description of these subtests).

The Spatial Relations (SR) subtest is part of the Perceptual Memory Task, which is a battery of tests developed for the purpose of assessing neuropsychological, educational, and vocational abilities in individuals with certain handicapping conditions (McCarron & Dial, 1986). For this particular subtest, subjects are asked to observe a card picturing blocks arranged in a certain configuration for ten seconds. Following the ten seconds, the card is removed and the subject is asked to reproduce the design in a three-dimensional fashion using wooden blocks. This task assesses immediate visual recall, ability to transform structures from two-dimensional to three-dimensional orientation, and constructional abilities (McCarron & Dial, 1986). Standard scores (mean = 100, SD = 15) were recorded and used in selected analyses for the SR subtest.

Sensory-Motor: The Bender Visual Motor Gestalt Test is a measure of visual-motor integration skills that involves copying nine geometric designs derived from "Gestalt Psychology." The BVMGT was scored using the Koppitz method (Koppitz, 1975). Subjects were also asked to recall and localize as many of the designs as they could remember following a fifteen-minute time interval. These recall and localization raw scores were also included in selected analyses.

The Haptic Visual Discrimination Test (HVDT) is a measure of sensory-integration, namely that of vision and various touch and movement senses. Subjects are asked to discriminate objects of various shape, size, texture, and configuration with first their dominant, then nondominant hand by simultaneously viewing a choice of objects on a card. The HVDT consists of a cloth screen to block the subject's view of the objects they are feeling, a series of different shaped, sized, and textured objects for them to feel, and a scoring sheet. Higher cortical functions involving the organization of multiple sensory inputs appear to be related to this task. These functions are processed in the parietal-occipital regions of the brain. Damage to these areas results in delayed learning (McCarron & Dial, 1986). Standard scores (mean = 100, SD = 15) for the right side, left side, and an average of the two were recorded.

The McCarron Assessment of Muscular Development (MAND) is a test of motor skills. The Neuromuscular Development Index (NDI) is the composite standard score which addresses overall motor behavior. This index is broken into two components: a fine motor standard score and a gross motor standard score. These three scores were used in selected analyses.

The MAND is comprised of five fine motor tasks and five gross motor tasks.

McCarron and Dial (1986) suggest that motor behavior can be broken down into four

components: (a) speed and direction of movement, (b) coordination of movement, (c)

strength, and (d) balance and posturing. These areas are further addressed in Appendix B

and in the MAND manual (McCarron, 1982).

Procedure

Clinical files were carefully reviewed from the past three years to search for

qualified subjects. The level of documentation of brain injury varied and thus priority was

given to cases in which there was clear documentation such as surgical and/or radiologic

reports (i.e., CT scans or MRI). In some cases there was documentation from the Texas

Rehabilitation Commission, although there may not have been accompanying medical

records. Table 2 (Appendix C) lists level of documentation obtained. Finally, self-reported

medical history or report by others (significant other or family member) was also included

if the injury resulted in a loss of consciousness or other symptoms clearly related to brain

injury such as memory problems, attentional difficulties and/or emotional lability. A

separate data sheet was utilized for each subject in which the details of the injury were

recorded (e.g., etiology, age at onset, treatment, medication, and prognosis, as available).

The testing procedure for control subjects was essentially the same as that which

the experimental subjects underwent in the clinical office. Initially subjects read and signed

an informed consent form (Appendix A). Subjects were then provided with a brief

description regarding the purpose of their participation in the study. They were also

provided with information regarding the intended use of their test scores as normal control

group data. The subjects were given a general description of specific tests prior to the evaluation; e.g., assessment of problem-solving abilities, perceptual functions, and motor skills. Furthermore, the subjects underwent a clinical interview identical to the one given to the experimental subjects. Well-trained doctoral students in psychology collected and scored the control group data. Subjects who were students were provided with extra credit and an optional opportunity to participate in a one-day workshop focusing on development and applications of the MDS.

Demographic data were analyzed to determine whether or not any general group differences existed. T-tests were used to determine if the groups differed in age and education level in years. Chi-square analyses were used for categorical variables including gender, ethnicity, and handedness.

Data were submitted to analyses of variance (ANOVAs) to analyze group differences on selected VSC and all SM measures. Analyses of covariance (ANCOVAs) were conducted for individual VSC measures for which no education-corrected norms were available (FSIQ, VIQ, PIQ, AA, LCM, LNL, and SR). Discriminant function analysis was utilized for the major analyses of the present study. Typically, the validation of neuropsychological test batteries has been performed through mathematical derivation of a classification function using discriminant function analysis to predict group membership (Dial, 1983). In studies which serve to validate neuropsychological test batteries, this is achieved by classifying subjects as brain-damaged versus non-brain-damaged prior to the analysis. Subjects are classified apriori based upon which group they were assigned to considering their medical history (e.g. whether or not they have a history

of acquired brain injury). The classification function is then applied to each subject and the percentage of accurate classifications (referred to as the hit rate) is computed. This procedure was therefore used for the major analyses in the present study.

Both forced entry and stepwise discriminant analyses were utilized in the present study. These methods of analysis will facilitate comparisons of the expanded MDS to other commonly used neuropsychological test batteries such as the Halstead Reitan and Luria Nebraska Batteries. A leave-one-out classification procedure (similar to jackknifing) was also utilized to estimate shrinkage of discriminant models used to correctly classify subjects into their known group membership. In the leave-one-out classification procedure, each case is classified by the functions derived from all cases other than that case. Otherwise, bias enters into classification because the coefficients used to assign a case to a group are derived, in part, from that particular case (Tabachnick & Fidell, 1989). Relative high levels of classification accuracy with limited shrinkage in the models can be interpreted as initial evidence of the revised and expanded MDS for application in clinical neuropsychological evaluation and rehabilitation applications of the system.

CHAPTER 3

RESULTS

The data were submitted to discriminant function analyses to test the major hypotheses of the present study. Analyses of variance (ANOVAs) and analyses of covariance (ANCOVAs) were conducted to evaluate group differences among all independent measures. Demographic data were analyzed using T-tests (age and education) and Chi-square analyses (gender, ethnicity, and handedness). Tables 3 and 4 (Appendix D) present analyses of demographic data.

As shown in Table 3 (Appendix D) non-significant differences were observed for handedness χ^2 (1, $\underline{N}$ = 201) = .046, $\underline{p}$ > .05 and race χ^2 (3, $\underline{N}$ = 201) = 7.27, $\underline{p}$ > .05. A significant difference was observed for gender χ^2 (1, $\underline{N}$ = 201) = 18.21, $\underline{p}$ < .001. As seen in Table 4 (Appendix D) significant group differences were also observed for age $\underline{t}$(199) = -2.604, $\underline{p}$ < .001, and education $\underline{t}$(199) = 9.153, $\underline{p}$ < .001. Although significant group differences were observed for gender, age, and education, it is important to note that scores on most independent measures were based upon demographic corrected norms (age, gender, and education). Therefore, the observed demographic differences between the groups do not significantly limit the findings of the present study.

The means, standard deviations, and analyses of variance (ANOVAs) for components of the Verbal-Spatial-Cognitive factor are presented in Table 5 (Appendix E). As shown, significant differences were observed for selected VSC variables utilized in the present study (BCTTSCORE, TRAILSAT, TRAILSBT, and ALGO7) between the brain-damaged and non-brain-damaged normal control group. Results of ANCOVAs for variables not corrected for education are presented in Table 6 (Appendix E) (FSIQ, VIQ, PIQ, AA, LCM, LNL, and SR). As shown in Table 6, significant group differences were observed on all variables when the effect of education was controlled.

The means, standard deviations, and ANOVAs for the Sensory-Motor measures are presented in Table 7 (Appendix F). As shown in Table 7, significant differences between groups were also observed for all SM variables used in the present study (BVMGTE, BVMGTL, BVMGTM, HVDTAVG, NDI, FINE, and GROSS). A combined group correlation matrix is presented in Table 8 (Appendix G) for all VSC and SM variables.

Results of a forced entry discriminant function analysis using seven global factor MDS variables (FSIQ, BCTTSCORE, TRAILSAT, TRAILSBT, BVMGTE, HVDTAVG, and NDI) are presented in Table 9 (Appendix H). Overall, 83.1% of cases were correctly classified from the original grouped cases and 82.1% were correctly classified with a leave-one-out classification procedure. 84.4% of the control subjects and 82.5% of the brain-damaged subjects were correctly classified for original grouped cases. Results of the leave-one-out classification yielded similar results: 84.4% of controls and 81.0% of brain-

damaged correctly classified. This indicated relatively little shrinkage upon cross-validation.

Standardized canonical discriminant function coefficients are presented in Table 10 (Appendix H). The characteristics of the function and a structure matrix that provides pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions are presented in Table 11 (Appendix H). Examination of the structure matrix reveals high relative contributions from assessment of overall motor function (NDI; .846), intelligence (FSIQ; .716), and sensory integration functions (HVDTAVG; .644). Cognitive motor speed (TRAILSAT; .561) followed by cognitive flexibility (TRAILSBT; .466) represent moderate contributions. Finally, measures of nonverbal abstract reasoning (BCTTSCORE; .349) and visual-motor integration (BVMGTE; -.336) are among the least discriminating variables.

The stepwise procedure utilizing the same seven global factors revealed two variables (NDI and FSIQ) which interacted to correctly classify 84.1% of the original grouped cases. The leave-one-out classification procedure also resulted in a correct classification of 84.1% indicating no shrinkage upon cross-validation. Specifically, 79.7% of controls and 86.1% brain-damaged original grouped cases were correctly classified. Likewise, 79.7% of controls and 86.1% of brain-damaged cross-validated grouped cases were correctly classified. The classification accuracy matrix for the stepwise model is presented in Table 12 (Appendix I). Table 13 (Appendix I) presents the standardized canonical discriminant function coefficients for the two factors that were retained. The characteristics of the function and structure matrix are presented in Table 14 (Appendix I).

The structure matrix presents the loadings of each variable. As described above, significant contributions are made by measures of overall motor function (NDI; .879) and intelligence (FSIQ; .744). Although not retained in the stepwise analysis, a relatively high contribution from a measure of sensory integration is observed (HVDTAVG; .484). Cognitive motor ability (TRAILSAT; .418) followed by cognitive flexibility (TRAILSBT; .396) contribute less to the overall discrimination between groups. Finally, measures of visual-motor integration abilities (BVMGTE; -.312) and nonverbal abstract learning (BCTTSCORE; .259) are the least contributing variables.

Table 15 (Appendix J) presents the classification results from a forced entry discriminant function analysis for a comprehensive model (15 variables) including various components of the global factor variables utilized in the previous analyses (VIQ, PIQ, BCTTSCORE, TRAILSAT, TRAILSBT, AA, LCM, LNL, SR, BVMGTL, BVMGTM, HVDTAVG, FINE, GROSS, and ALGO7). Results indicated 89.6% correct classification of original groups and 87.1% correct classification for cross-validated grouped cases. 85.9% of normal controls and 91.2% of brain-damaged original grouped cases were correctly classified compared with 85.9% controls and 87.6% cross-validated grouped cases. Table 16 (Appendix J) presents the standardized canonical discriminant function coefficients for this analysis. Characteristics of the function and the structure matrix are presented in Table 17 (Appendix J). Results indicate relatively high contributions from measures of active verbal learning and verbal-contextual memory (LNL; .623 and LCM; .544) as well as components of motor behavior (FINE; .579 and GROSS; .616). Following this, sensory integration (HVDTAVG; .539) in addition to verbal and nonverbal

intelligence (VIQ; .517 and PIQ; .512) are seen as moderate contributors. Cognitive-motor skills (TRAILSAT; .470) and phonemic analysis (AA; .442) are followed by measures of cognitive flexibility (TRAILSBT; .390), spatial localization (BVMGTL; .383), spatial memory (BVMGTM; .360), and visuo-spatial constructional abilities (SR; .360). Finally, nonverbal abstract learning (BCTTSCORE; .292) and an algorithm that is typically sensitive to general brain dysfunction (ALGO7; -.199) are seen as the least discriminating variables.

Results of the stepwise procedure utilizing the same 15 variables resulted in 86.1% correct classification for original grouped cases and 85.6% correct classification for cross-validated groups based upon retention of four variables: LNL, GROSS, LCM, and FINE. 82.8% of the normal controls and 87.6% of the brain-damaged original grouped cases are correctly classified. 82.8% of controls and 86.9% of the brain-damaged cases were correctly classified using the leave-one-out classification procedure. These results are presented in Table 18 (Appendix K). Table 19 (Appendix K) presents the standardized canonical discriminant function coefficients and the structure matrix; characteristics of the function are presented in Table 20 (Appendix K). As shown, active verbal learning variables and verbal memory (LNL; .665 and LCM; .581) in addition to measures of motor behavior (GROSS; .657 and FINE; .618) are significant contributors as they were retained in the analysis. Verbal and nonverbal intelligence (VIQ; .467 and PIQ; .449) are followed by sensory integration functions (HVDTAVG; .412) producing moderate contributions. Cognitive flexibility (TRAILSBT; .370), phonemic analysis (AA; .366), cognitive motor speed (TRAILSAT; .338), spatial localization (BVMGTL; .336) and

visuo-spatial constructional abilities (SR; .332) provide the next best contributions.

Finally, measures of spatial memory (BVMGTM; .286), nonverbal abstract learning

(BCTTSCORE; .239) and an algorithm that is typically considered to be a sensitive

indicator of general brain dysfunction (ALGO7; .010) comprise the least contributing

factors.

CHAPTER 4

DISCUSSION

Overall, the results of the present study support the utility of the expanded

McCarron-Dial System (MDS) for diagnosis of neuropsychological dysfunction in adults

using the Verbal-Spatial-Cognitive (VSC) and Sensory-Motor (SM) components of the

battery. The tests that were added to the original battery improved its sensitivity in

discriminating brain-damaged from non-brain-damaged individuals thus providing further

evidence of its utility as a neuropsychological diagnostic test battery. Significant group

differences were found among all of the VSC and SM tests suggesting a potential relative

contribution to accurate diagnosis from all components of these two factors. The findings

are also promising regarding the utility of the expanded battery for individual treatment

and rehabilitation planning due to a high degree of diagnostic accuracy. However,

continued research will be needed to further evaluate the potential contribution of the

MDS Emotional-Coping factor to accurate differential diagnosis as an assessment of this

factor was not included in the present study. The following is a discussion of results from

the present study, limitations, and recommendations for future research.

An evaluation of the discriminative power utilizing the broadest dimensions of

neuropsychological functions assessed by the MDS revealed significant results. These

broad dimensions included overall intelligence (WAIS-R FSIQ), cognitive-motor speed

(Trails A), cognitive flexibility (Trails B), nonverbal abstract learning (Booklet Category

Test), visual-motor integration abilities (Bender Visual Motor Gestalt Test), tactile-visual

integration abilities (HVDT), and overall motor skills (MAND NDI). Specific results

indicated that these global variables successfully discriminated (83.1% correct

classification) between neuropsychologically impaired adults from adults without cerebral

impairment, thus supporting the first hypothesis. The classification rates were similar

within both the brain-damaged (82.5%) and non-brain-damaged normal control (84.4%)

groups. As such, these results support the utility of the MDS global factors for

determining the presence of cerebral impairment in brain-damaged individuals as well as

the absence of impairment in non-brain-damaged controls. Compared with previous

research, this represents an improvement in the classification of control subjects. In terms

of overall classification accuracy, these results are consistent with previous findings from

the original battery and further support the utility of the expanded version of the system as

a diagnostic neuropsychological test battery (Chan & Dial, 1987; Dial, 1983; Dial, Chan &

Norton, 1990). The global model proved to be the most effective for maximizing

separation between the two groups while using a minimum number of variables.

Therefore, the inclusion of measures of these broad areas in a comprehensive

neuropsychological assessment is considered essential in determining the presence or

absence of brain damage that may impact an individual's functional abilities.

Analysis of relative contributions of the MDS global variables revealed that a

comprehensive assessment of motor behavior (NDI) and a traditional evaluation of

intelligence (WAIS-R FSIQ) were the most important discriminators between brain-damaged individuals and non-brain-damaged controls. The significant contribution of overall motor functioning that was observed in the present study can be explained, at least in part, by the sensitivity that damage to many different areas of the brain typically has on these functions. Motor abilities are mediated by a very diverse system with contributions from a variety of cortical, subcortical, and lower motor structures. As such, lesions occurring in many different locations of the brain (depending upon the nature of the injury) often impact motor functioning. Thus, as the present results indicate, such measures would be expected to provide excellent diagnostic information in terms of separating brain-damaged from non-brain-damaged individuals. In contrast, other measures included in the present study may be relatively more sensitive to the effects of lesions to specific areas of the brain. Thus, these measures would be expected to improve the discrimination between brain-damaged and non-brain-damaged individuals by identifying individuals within the group that have more discrete or focal lesions. For example, measures of tactile-visual integration functions (HVDT) will be most sensitive to damage in the parieto-occipital association areas and, as such, may be more discriminating of individuals with specific damage in these areas, in contrast to individuals with frontal lobe damage in which perceptual functions may remain intact. A "system's approach" such as advocated by the MDS would appear to be the most effective approach to maximizing the accuracy in neuropsychological diagnosis. This approach assumes that damage to a particular area in the brain will disrupt a system and thus affect a variety of behaviors. Systematic evaluation

of different behaviors will allow for hypotheses to be generated regarding disruption to certain areas of the brain which have a role in the execution of that behavior.

Consistent with the literature, the present findings also support the utility of including a measure of overall intellectual ability (WAIS-R) as part of a comprehensive neuropsychological test battery. It has been well documented in the literature that certain subtests on the WAIS-R are relatively more susceptible to the effects of cerebral impairment than others (referred to as "don't hold" versus "hold" tests respectively). Therefore, it would be expected that the overall score (FSIQ) will decline when the brain is injured due to a decline in scores on the "don't hold" subtests. This is consistent with the findings from the present study. However, an interesting, related finding is the relatively lower discriminative power of an algorithm (Algorithm 7) derived exclusively from the "hold" and "don't hold" subtests from the WAIS-R versus the Full Scale IQ. This algorithm is typically considered to be a good general indicator of brain damage when taking into account age of onset and chronicity. It is computed by taking the average of age-corrected scores from the Arithmetic, Digit Span, and Digit Symbol ("don't hold") subtests subtracted from the average of age-corrected scores for the Comprehension and Picture Completion ("hold") subtests. Although a significant group difference was observed based upon this algorithm, it was not retained in the stepwise analysis. This implies that the general factor of intelligence may be more sensitive to the effects of brain damage (at least within the context of a mixed group) than any particular specific factor. It is likely that the WAIS-R FSIQ is highly diagnostically significant because it includes the evaluation of a variety of specific functions tapping different functional neurological

systems within the brain. Considering the variety of different brain injuries within the sample studied, improved discrimination would be expected when measuring a greater number of discrete behaviors because of their mediation by many different underlying brain structures. On the other hand, the relatively lower discriminative ability for Algorithm 7 versus the FSIQ observed in the present study may have been due to the nature of the sample. "Don't hold" subtests tend to be more sensitive to acute conditions and most of the brain-damaged subjects in the present study were in the mid-acute to chronic stages. This suggests that different variables may be more important in the discrimination of brain-damaged from non-brain-damaged individuals depending upon other factors such as chronicity. Investigation of this issue is recommended in future research. The present findings support relatively stronger discriminative ability of the general intellectual factor versus specific measures reflected in Algorithm 7 when the sample being evaluated consists of primarily individuals in the late acute to chronic stage of injury.

Surprisingly, traditional measures of cognitive-motor speed, cognitive flexibility, and visual-motor integration ability were the least discriminating variables between the two groups in this sample. This has important implications for neuropsychological screening assessments as tests of these functions have historically been considered to be highly diagnostically significant and are often included in screening batteries. Indeed there were significant group differences observed on these variables in the present study suggesting at least moderate discriminative power. However, their relative contributions were less than would be expected considering the support they have received in the literature. It may be that these tests were redundant with other MDS measures and that

the specific MDS variables that were retained in the stepwise procedure were more powerful discriminators between the two groups. However, should this finding be validated in future research, their inclusion as integral components of neuropsychological screening batteries may be questioned.

When the global factors were separated into their specific functional measures, a more comprehensive model was produced. Significant group differences were observed among all VSC and SM measures included in this analysis, and inclusion of all variables in a forced entry discriminant function analysis resulted in 89.6% overall correct classification of subjects. These results suggest even greater diagnostic ability for the MDS when tests that were added to the original MDS (particularly, Letter Number Learning, Language Comprehension and Memory, Auditory Analysis, and Spatial Relations) are included. In fact, results indicate that the specific tests that were added to the original battery which assess active verbal learning and verbal-contextual memory were among the highest discriminating factors. From a theoretical perspective, discriminative power of active verbal learning and verbal-contextual memory would be predicted since this type of active cognitive processing is thought to be mediated by the frontal region (attentional component) as well as more posterior temporoparieto-occipital contributions. Since a variety of these regions of the brain are quite susceptible to the effects of brain injury, particularly in common head-in-motion injuries, the aforementioned measures would be expected to be diagnostically significant. Indeed, the largest percentage of subjects in the present study were identified as having sustained head-in-motion injuries suggesting a high likelihood of widespread diffuse damage and involvement of both anterior frontal, as well

as, posterior association regions. It is also possible that the sensitivity of measures of active verbal learning (including verbal functions) may also be a reflection of the population sampled in the present study. It has been well documented in the literature that measures of novel nonverbal learning, such as the Category Test, are quite sensitive to the effects of cerebral impairment (Reitan & Wolfson, 1993). Although this variable was not among the most powerful discriminators in the present study, the important general notion is that active learning, whether verbal or nonverbal, is particularly sensitive to the effects of brain injury. The finding that an assessment of active verbal and nonverbal processing is important in the discrimination of brain-damaged from non-brain-damaged individuals is particularly relevant since few existing batteries include measures of both of these functions. It would appear to be particularly important to add measures of active verbal processing and verbal memory to existing neuropsychological test batteries to assure greater diagnostic validity. As such, the present results have important implications regarding other commonly used test batteries. For example, one criticism of the Halstead-Reitan Neuropsychological Test Battery has been that it does not include an adequate evaluation of memory functions nor is there an assessment of active verbal learning.

When contrasted to the significant contributions observed from measures of active verbal processing, more traditional measures of verbal intelligence (WAIS-R VIQ) were found to contribute less in the discrimination between the two groups in the present study. This is not surprising since many of the subtests that comprise the WAIS-R VIQ measure static verbal functions. As mentioned previously, certain subtests on the WAIS-R have been identified as "hold" tests meaning that they are relatively robust to the effects of brain

injury. In fact, most available tests of verbal functioning assess mainly static verbal abilities as opposed to active verbal processing. Therefore, it is not surprising that these measures would be less likely to discriminate a population of brain-injured from non-brain-injured individuals. This phenomenon has led to a misconception that verbal abilities in general are less impacted by brain injury than non-verbal abilities. If "active verbal learning" measures, such as those included in the present study are used, they appear to be at least as effective as nonverbal measures in discriminating between brain-damaged and non-brain-damaged groups. Nonetheless, it is important to include measures of static verbal abilities for other reasons such as estimating premorbid ability.

Consistent with findings regarding global motor functions, specific measures of both fine and gross motor skills were also identified as significant contributors to the discrimination between individuals with brain damage and normal, non-brain-damaged controls in the stepwise procedure. This further confirms that there are significant contributions from specific aspects of motor functions assessed by the MAND. These results suggest that measures of many different aspects of motor behavior are important diagnostic indicators and as such appear to be essential as components of neuropsychological test batteries.

Results of the present study indicate that the expanded MDS has demonstrated improvements over previous versions of the battery providing stronger evidence regarding its utility for neuropsychological assessment and subsequent treatment planning. Therefore, the second hypothesis of the present study was supported. Although overall classification rates were similar to previous versions of the MDS, stepwise analysis

revealed that newly added subtests measuring active verbal learning and verbal contextual memory were among the most important in the differentiation of the two groups. Furthermore, as mentioned previously, the classification rate actually improved for correct identification of control group members, thus supporting greater diagnostic ability of the expanded version of the system.

Furthermore, the expanded MDS demonstrated classification rates comparable to the Halstead-Reitan Neuropsychological Test Battery and the Luria-Nebraska Neuropsychological Battery providing support for the third hypothesis of the present study. The future of the MDS appears promising as its utility as a predictor of work and independent living has already been demonstrated. In contrast, the other major batteries have not demonstrated this practical utility. It is interesting to note that components of the Halstead-Reitan battery that are included in the MDS were among the least discriminating variables in the present study supporting the diagnostic utility of other tests within the battery. The present results nonetheless indicated that certain subtests of the Halstead-Reitan battery are diagnostically useful (Trails A, Trails B and Booklet Category Test) as significant group differences emerged.

Since the present findings support the diagnostic utility of the expanded MDS, they consequently also suggest positive support regarding treatment planning abilities on an individual level. The addition of subtests measuring a broader range of functional behaviors enables the battery to better identify individual strengths and limitations that are essential for rehabilitation planning efforts. The present results suggest relevant contributions from all areas assessed with the expanded MDS supporting the utility of

each measure in the battery for providing an individual comprehensive neuropsychological profile. It is important to note that the purpose of the present study was for validation purposes only. There was no effort to establish specific cut-off scores for the purpose of diagnosis. Rather, the present findings argue for an appreciation of individual factors in case interpretation. For example, consideration of premorbid factors, historical information, and behavioral observations in addition to neuropsychological test performance are all factors which contribute to diagnosis and subsequent treatment planning. For example, an individual with a High Average to Superior premorbid IQ may score within the Average range on an IQ test following a brain injury. It is also possible that this individual's neuropsychological profile may be negative for other signs of brain dysfunction due to a high level of premorbid ability. However, consideration of historical information (e.g., education, employment history) and behavioral observations may reveal a change in the individual's functional level following the brain injury. This example illustrates how interpretation solely based upon neuropsychological test results could lead to erroneous conclusions.

Although the results of the present study suggest strong discriminative power of the MDS in distinguishing brain-damaged from non-brain-damaged individuals, it was also necessary to perform a systematic evaluation of cases that were misclassified in order to identify potential confounding variables. Identification of common characteristics of misclassified cases could potentially assist in improving the assessment system and the research design for future studies. For example, potential problems that may affect misclassification include similarities in age, education, or overall level of intellectual

ability. It is also possible that cases were originally misidentified such that some "normal controls" may actually have had a history of either congenital or acquired brain injury that was not reported or was never medically diagnosed. Furthermore, it is possible that subjects may have been included in the brain-damaged group erroneously without sufficient evidence to support the presence of cerebral impairment. For example, lack of sufficient medical documentation may argue against inclusion of so-called "marginal cases" in the brain-damaged group, particularly in cases of suspected mild injury.

Evaluation of misclassified normal control subjects in the present sample revealed evidence of possible mild brain impairment (e.g. self-reported concussions) in a few of these subjects; their misclassification to the brain-damaged group may have resulted from an undiagnosed disease, injury, or trauma. Thorough evaluation of the brain-damaged subjects that were erroneously classified as non-brain-damaged did not appear to share any common features. However, some of the cases had reportedly only "mild brain injury" such as postconcussive syndrome. Therefore, it is possible that the sensitivity of the MDS for diagnosis of brain dysfunction may be limited in relatively mild cases; this would be a finding consistent with other neuropsychological test batteries at the present time (e.g. false negatives). This observation suggests that further research is necessary to improve the ability to detect mild brain injury using neuropsychological tests. Finally, it may be that inclusion of the MDS Emotional-Coping factor (EC) assessments in future studies will improve the system's ability to correctly classify cases such as those that were missed by the present method. The MDS behavioral and emotional measures may have been better able to capture characteristics of the brain-injured subjects not observed in the non-brain-

damaged control subjects. The omission of the EC factor is obviously considered to be a limitation of the present study, and it is thus strongly recommended that this factor be included in future research.

Another limitation of the present study was the inability to obtain a sufficient number of demographically similar control subjects to those of the brain-damaged group. An attempt was made to match control subjects with the demographic characteristics collected for the brain-damaged group. This attempt was only partially successful due to difficulties recruiting subjects meeting very specific criteria (e.g., left-handed, African American, male, etc.). However, demographic corrected norms were utilized, when available, to adjust for group differences. Specifically, age, gender, and education corrected norms were used on tests from the Halstead-Reitan battery including Trail Making Parts A and B, and the Booklet Category Test. Age-corrected scores were used for WAIS-R subtests. Age-corrected norms were also used for the HVDT and the MAND. Furthermore, gender based norms were used for appropriate subtests on the MAND (grip strength and jumping). It is important to note that there is no evidence suggesting an impact of education on the HVDT or the MAND, therefore no other adjustments to these tests were considered necessary. Unfortunately, some of the measures that were included do not have demographically corrected norms available and may have been impacted by factors such as age and/or education. It has been well documented in the literature that education level has been correlated with verbal functions including certain subtests on the WAIS-R (Information and Vocabulary). It is also therefore likely that education level has an impact on performance of other verbal subtests,

such as Language Comprehension and Memory. Although this may be considered a potential limitation of the present study as it may limit generalizability of results, when education was controlled for statistically significant group differences on these measures were still present. This suggests that the impact of group differences in education were minimal despite significant correlations obtained.

Since the discriminative validity of the expanded MDS was proven to be significant, an attempt was also made to evaluate differences of subgroups within the brain-damaged group. This was considered important as it could help to identify the utility of the MDS in terms of answering more specific diagnostic questions such as localization of brain lesions and chronicity. However, due to the nature of the sample in the present study, this attempt was not successful. Specifically, it was found that 81.8% of the sample had diffuse damage while only 10.2% had lateralized damage primarily involving the right cerebral hemisphere and 7.3% with primarily left hemisphere involvement. Thus, the sample for evaluating lateralization was too small. Regarding chronicity, a similar problem emerged. As most of the brain-damaged subjects were referred from the Texas Rehabilitation Commission, many were past the point of acute injury and several were actually many years post-injury. Specific analyses revealed that only 21.9% of the subjects were evaluated less than two years post injury, 21.2% were seen between two and five years, while 42.3% were evaluated five years post injury. Unfortunately, this again produced a sample size smaller than would be recommended for meaningful analysis. Expanded samples are needed in future research to address these issues.

Conclusions

In conclusion, results of the present study suggest that the expanded MDS shows

promise as a neuropsychological test battery. The present findings suggest a high degree

of diagnostic discrimination between brain-damaged and non-brain-damaged individuals.

Evidence for improvements in diagnostic accuracy due to inclusion of tests measuring

active verbal processing was observed. In addition, contributions from measures assessing

overall intellectual ability and motor behavior were identified as important indicators of

diagnostic differentiation at a global level. The present findings are generally consistent

with previous results from the original MDS battery and are based on a broader sampling

of both brain-damaged and non-brain-damaged subjects. Therefore, these findings provide

positive support for continued research regarding the utility of the MDS as a diagnostic

instrument, as well as, particular contributions that perceptual-motor, active verbal

learning, and overall intellectual ability have in differentiating various types of brain

disorders. The expanded MDS battery includes a wider array of particular cognitive and

perceptual motor functions that are assessed, consequently providing a broader base of

information from which individual strengths and/or limitations may be identified and thus

addressed programmatically through treatment or rehabilitation efforts. Additional

predictive validity studies of the expanded MDS are needed to determine the relationships

of individual assessment profiles to specific rehabilitation outcomes. Furthermore,

inclusion of measures from the EC factor will be essential to evaluate contributions of

these variables to diagnostic accuracy. Issues identified by the present findings regarding

improvements in research design should also be addressed in future research. Specifically,

efforts should be made to better match control subjects to the demographic characteristics observed within the brain-damaged sample to control for potential confounding variables such as education level. Assuming continued positive research support, the expanded MDS appears to be a potentially useful assessment battery for both clinical neuropsychological diagnosis and rehabilitation program planning.

APPENDIX A

INFORMED CONSENT

Informed Consent

I agree to participate in a study investigating the usefulness of a standardized neuropsychological test battery in discriminating brain-injured from non-brain-injured adults. Specifically, this study will attempt to determine the validity of the Expanded McCarron-Dial System as a potential neuropsychological test battery for diagnostic and treatment planning purposes.

As a participant, I understand that my involvement is contingent upon my meeting the following criteria:

1. I must be between the ages of 16 and 60

2. I must be in good physical health

3. I must have no history of:

    a. brain damage (traumatic brain injury; seizures)

    b. alcohol or chemical dependency

    c. sensory impairment (glasses & hearing aids are acceptable if they

       fully correct and must be worn during the study as needed)

    d. diagnosed or suspected learning disability or attention-deficit disorder

I also understand that my participation will include approximately six hours of neuropsychological evaluation. This evaluation will include tasks assessing general intelligence, problem solving, academic achievement, sensory and motor functions, memory, and attention. I will also be asked to provide demographic information including my age, race, education level, and occupation, as well as information regarding my spouse's and/or parents' education levels and occupations. I understand that all

information will be confidential and anonymous. I will be assigned a three-digit code which will replace my name on all data collection forms.

I will be allowed breaks as needed, including up to one hour for eating lunch or dinner. I may bring my lunch or dinner to eat midway through the evaluation period. I understand that there is no personal risk or discomfort directly involved with this research. Furthermore, I understand that my participation is voluntary and that I am free to withdraw my consent and discontinue participation in this study at any time without penalty, prejudice or loss of benefits.

If I have any questions or problems that arise in connection with my participation in this study, I should contact either Beth Colaluca (Health Psychology student investigator) or Dr. Dial (project director) at (972) 570-7860.

_____   _____

Signature   Date

This project has been reviewed and approved by the UNT Committee for the Protection of Human Subjects (817) 565-3940.

APPENDIX B

TEST DESCRIPTION

Test Description

<u>Verbal-Spatial-Cognitive</u>

<u>Auditory Analysis and Sound Repetition.</u> In this subtest, the subject is asked to repeat word-like sounds presented by audiotape or by the examiner. This test requires attention, auditory detection, acoustic analysis and basic expressive language abilities. With reference to Luria's Functional Systems' Theory, tasks involved in this subtest would be primarily mediated by the auditory detection and recognition zones of Unit II with contributions from Unit I (attention and concentration) and Unit III (motor speech). The Auditory Analysis subtest was found to be reasonably reliable (test-retest r = .90; interrater reliability = .85).

<u>Language Comprehension and Memory.</u> Stories are presented by audiotape, or read by the examiner, and are followed by content-related questions. This test requires receptive language, memory for verbal detail, and basic expressive language. According to Luria's model, Unit II secondary zones for processing auditory and verbal information would be involved; additional contributions from the parietal integration area (tertiary zone) of the left cerebral hemisphere would be important. Unit II (receptive) and Unit III (expressive) language functions with contributions from higher order verbal/auditory memory mediated by Unit II are included. The language comprehension subtest revealed a test-retest reliability coefficient of .92.

<u>Letter-Number Learning.</u> Paired letters and numbers are presented in series. The individual is asked to repeat each series presented. Repeated trials (1 to 5) are given until a series is correctly recalled. Unit II left hemisphere structures which mediate verbal

memory and learning are involved. Sequencing and organizing functions of Unit III

mediate the oral response. Adequate arousal, attention and concentration (Unit I) also play

a role in the performance of this task. An alternate form of this subtest was used as a

method of estimating reliability. The resulting correlation between the two forms was .90.

Spatial Relations. Cubes are used to reconstruct printed cube patterns ordered in a

simple-to-complex progression. The task involves two to three dimensional transformation

(Unit II, right occipito-parietal areas); immediate visual pattern recall (Unit I hippocampus

and right basilar temporal areas); and constructional praxis (Unit III motor functions and

planning).

Sensory-Motor

Haptic Visual Discrimination Test. Tactile discrimination involves the manipulation

of objects in the hand to discriminate their particular shape, size, texture, and spatial

arrangements and to conceptually integrate these sensations to form an accurate mental

representation of the total object. Geometrically shaped and textured objects are obscured

from the visual field and manipulated in one hand. While feeling and manipulating the

object in the hand, the person attempts to visually identify a correct representation of the

object on a photographic chart. While haptic-visual discrimination is partly a cognitive

function and associated with intelligence, the ability to recognize objects by haptic

manipulation primarily involves sensory (cutaneokinesthetic) and visual processes. The

test measures the ability to integrate tactual and visual information. Higher cortical

functions involved in organization of sensory input and conceptualization appear related to

performance of haptic-visual tasks. From a psychological perspective, the task requires a synthesis and integration of particular elements into a unified whole.

Tactile-visual discrimination and integration skills are processed by the parietal-occipital areas of the brain. Higher cortical functions involving organization and integration of bimodal sensory information are involved in the performance of the task (Luria's Unit II, primary detection, recognition, and association of visual and haptic-kinesthetic sensory information). The association of complex tactile and visual information requires the integration of these sensory inputs by the tertiary zones of Unit II (angular and supramarginal gyri). These same areas also participate in the mediation of very complex cognitive functions, perceptions, learning, and performance of language and academic tasks. Therefore, tactile deficits in either or both sides of the body may be identified by the HVDT and subsequently related to educational and vocational potential. Thus, there is a relationship between the performance scores on instruments which assess parietal-occipital functioning and cognitive skills of people with disabilities. Poor HVDT performance on the right as contrasted to the left side of the body may suggest neuropsychological dysfunction involving the left, language hemisphere. This disparity is most obvious in individuals with known traumatic lesions of this hemisphere but can also be observed in some cases of learning disabled individuals. These persons may perform poorly in basic academic subjects such as reading, spelling, and arithmetic due to a congenital anomaly of development involving the left parietal associative area. In contrast, lateralized deficits to the right cerebral hemisphere may be suggested by low left hand performance. In these cases, problems in spatial analysis and specific learning disabilities

involving poor academic performance in arithmetic and probably expressive writing may be observed. Tactile discrimination difficulties may also lead to problems with basic prevocational and vocational skills such as appropriate use of small hand tools, discrimination among small parts and assembly tasks.

The HVDT materials consist of: a cloth screen to obscure the individual's vision of the hand used to manipulate the object; a series of geometric and textured shapes; a photographic identification chart; and scoring sheets. The HVDT is relatively easy to administer and score and has a reliability of .90 with a standard error of measurement of only 2.2. The individual's HVDT score may range from 0 to 48 correct responses and is used in constructing the individual program plans in education and rehabilitation. The predictive validity with work potential has been reported to range from .53 to .86.

McCarron Assessment of Motor Development. The MAND is the primary MDS measure used to assess the motor factor in vocational, educational and clinical neuropsychological assessment. The MAND consists of five fine and five gross motor tests combined to produce a total motor score. In vocational and educational evaluation of adolescents and adults, the MAND total raw score and separate raw score totals for the fine and gross motor sections are computed and used in developing individual program plans. Various factor scores and subtest scores from the MAND are also used in this process. In clinical neuropsychological assessment, different procedures are used to compute scaled scores for each subtest and standard scores for various MAND factors. Supplemental clinical procedures (such as alternating supination and pronation of the forearms, finger to thumb apposition, etc.) may be added in neuropsychological

assessment; but, the MAND is the only formal test used in the MDS to assess this factor. The MAND has demonstrated excellent reliability (test-retest correlation of .99) for use with brain damaged groups. The predictive validity between the MAND and work performance is significant (r = .70; p < .0001). The correlation coefficient between the MAND and residential program level is also significant (r =.51; p < .001).

Since many neuropsychological and vocational assessment procedures tend to redundantly measure only bimanual dexterity or hand strength, it is important to include a comprehensive yet efficient measure of neuromotor skills. The MAND provides such a comprehensive assessment of the individual's neuromuscular functioning. The following sections describe these factors:

Persistent Control. This factor is assessed by the Rod Slide and Finger-Nose-Finger subtests. This factor involves this integration of perceptual skills with the regulation of hand-arm movement. The tasks require controlled hand-arm coordination (cerebellum), the ability to focus attention while inhibiting extraneous motor movements (Unit I reticular formation and Unit II parietal area). Inadequate persistent control may also suggest poorly focused attention. In a vocational setting, depressed persistent control scores may be associated with poor quality in workmanship, tendencies to make frequent errors and increased risk for accidents.

Muscle Power. This factor is measured by the hand strength and jumping subtests. This factor involves the healthy functioning of the skeletal muscles reflecting timing and coordination. The greatest muscle power is elicited when the muscles are contracted simultaneously. The tasks include a measure of hand/arm strength and a

measure of leg strength. In children, poor muscle power may interfere with recreational

activities and participation in sports, thus leading to secondary social/emotional problems.

In a vocational setting, depressed muscle power may interfere with tasks that require

lifting, carrying, pushing, or pulling. In clinical assessment, reduced muscle power,

particularly to the upper body, may indicate cortical level brain damage (posterior frontal

lobes - Luria's Unit III).

Kinesthetic Integration. This factor is measured by the heel-toe walk and

the standing on one foot subtests and is defined as the control of balance and orientation

of the body in space. Performance on these subtests involves static balance and equilibrium

as well as dynamic balance with the integration of sensorimotor input from large muscle

systems. Deficits in balance and gross motor coordination may interfere with play and

recreational activities. Deaf and visually-impaired/blind individuals may experience

problems in kinesthetic integration. Work tasks which require extended reaching,

crawling, climbing, etc., may be hazardous or require individual accommodation. In

clinical diagnosis, severe deficits may be observed in persons with subcortical vestibular

system and cerebellar lesions.

Bimanual Dexterity. This factor is measured by the beads-on-a-rod and

nut-and-bolt subtests. Adequate performance on the bimanual dexterity factor requires

integration of proprioceptive and kinesthetic information with fine motor coordination of

both hands. The nut-and-bolt subtest requires the inhibition of movement in one hand

while simultaneously manipulating the fingers and wrist of the preferred hand (e.g.,

rotating thumb and wrist movements). A good score in this area requires precise bimanual

coordination. Deficits in bimanual dexterity have a negative impact on a wide range of daily living and work activities. Slow and uncoordinated performance may interfere with a variety of work tasks. Activities such as operating powered machinery may also be compromised. In clinical assessment, these deficits may be associated with lateralized lesions involving predominant impairment on one side of the body.

In addition to the four factors, specific MAND scores related to speed, strength, and fine motor coordination are combined to form a Hand Preference Index (HPI) for both the right and left hands. A measure of the ability to consistently alternate movement between the right and left sides of the body (diadico-kinesis) as well as a measure of hand fatigue are also described in the MAND manual. Results from all ten MAND subtests are converted to standard scaled scores by using normative tables. Norms for the MAND are available from ages 3-6 through older adults, thus developmental abilities as well as age-related regression can be evaluated. For vocational evaluation of older adolescents and adults, raw scores from the MAND are converted directly to standard scores (M = 100, SD = 15) for the general population. Norms for the neuropsychologically disabled are also available. The assessment procedures may be used with the sighted, deaf, or visually-impaired/blind populations. Certain MAND subtests are more sensitive to cortical lesions, while performance on other subtests is adversely affected by lesions of the basal ganglia, cerebellum, or brain stem; thus, the instrument is useful in differential diagnosis and leveling of lesions in the central nervous system.

Reprinted from the McCarron-Dial Evaluation System.

APPENDIX C

PATHOLOGY, ETIOLOGY, AND DOCUMENTATION

OF BRAIN DAMAGE

Table 1

Pathology/Etiology of Brain Damage

Pathology/Etiology	Number	Percentage
Closed head injury	83	61
Open head injury	5	3
Cerebral vascular accident	6	4
Non-congenital seizure disorder	10	7
Aneurysm	5	3
Tumor (with or without removal)	5	3
Encephalitis	2	1
Anoxia	2	1
Other diffuse damage	13	9
Multiple cause	6	4
Total	137	100

Table 2

Documentation of Brain Damage

Source	Number	Percentage
CT scan	14	10
MRI	4	3
EEG	7	5
Other medical records	25	18
TRC records	94	69

APPENDIX D

ANALYSES OF DEMOGRAPHIC VARIABLES

Table 3

Chi-Square Analyses for Brain-Damaged (BD) and Normal Control (NC) Groups

Demographic Characteristics

Variable	Chi-Square
Sex	$\chi^2(1, \underline{N}=201) = 18.21$***
Race	$\chi^2(3, \underline{N}=201) = 7.27$
Handedness	$\chi^2(1, \underline{N}=201) = .046$

*** $\underline{p} < .001$

Table 4

Means, Standard Deviations, and T-tests for Brain-Damaged (BD) and Normal Control (NC) Groups Demographic Characteristics

Variable	Brain-Damaged Mean/Std. Deviation	Normal Controls Mean/Std. Deviation	$t(199)$
Age	34.81/11.36	29.23/10.30	-3.336**
Education	11.46/2.58	14.86/1.61	9.684***

** $p < .01$. *** $p < .001$.

APPENDIX E

MEANS, STANDARD DEVIATIONS, ANOVAS AND ANCOVAS OF

VERBAL-SPATIAL-COGNITIVE MEASURES

Table 5

Means, Standard Deviations and ANOVAS for Brain-Damaged (BD) and Normal Control (NC) Groups Verbal-Spatial-Cognitive Measures

Variable	Brain-Damaged Mean/Std. Deviation	Normal Controls Mean/Std. Deviation	$F(1, 199)$
WAIS-R FSIQ*	86.47/10.46	100.93/9.08	90.43***
WAIS-R VIQ*	87.05/11.26	100.22/9.08	67.11***
WAIS-R PIQ*	87.96/12.14	102.20/10.25	65.98***
ALGO7	.92/1.24	.37/.92	9.91**
Trails A T-Score	37.97/11.13	50.07/9.85	55.46***
Trails B T-Score	41.79/11.57	51.92/9.03	38.21***
Booklet Category T-Score	37.52/8.12	44.38/12.65	21.47***
AA*	10.82/3.36	14.08/2.35	49.03***
LCM*	7.60/3.15	11.59/2.83	74.43***
LNL*	7.71/2.08	11.03/2.51	97.56***
SR*	90.42/22.18	108.47/17.82	32.53***

** $p < .01$. *** $p < .001$.

Note. * See results of ANCOVA (Table 6)

Table 6

Means, Standard Deviations, and ANCOVAS (Covariate: Education) for Brain-Damaged (BD) and Normal Control (NC) Groups Verbal-Spatial-Cognitive Measures

Variable	Brain-Damaged Mean/Std. Deviation	Normal Controls Mean/Std. Deviation	$F(1, 199)$
WAIS-R FSIQ	86.47/10.46	100.93/9.08	37.66***
WAIS-R VIQ	87.05/11.26	100.22/9.08	23.21***
WAIS-R PIQ	87.96/12.14	102.20/10.25	32.55***
AA	10.82/3.36	14.08/2.35	25.24***
LCM	7.60/3.15	11.59/2.83	36.84***
LNL	7.71/2.08	11.03/2.51	45.57***
SR	90.42/22.18	108.47/17.82	23.85***

** $p < .01$. *** $p < .001$.

APPENDIX F

MEANS, STANDARD DEVIATIONS, AND ANOVAS OF

SENSORY-MOTOR MEASURES

Table 7

Means, Standard Deviations, Analyses of Variance for Brain-Damaged (BD) and Normal

Control (NC) Groups Sensory-Motor Measures

Variable	Brain-Damaged Mean/Std. Deviation	Normal Controls Mean/Std. Deviation	$\underline{F}(1, 199)$
BVMGTE	1.76/2.20	.484/.908	19.84***
BVMGTL	3.49/2.16	5.39/1.82	36.93***
BVMGTM	5.15/1.99	6.70/1.32	32.56***
HVDT (Avg)	93.11/21.61	118.27/13.60	73.03***
NDI	79.96/15.64	107.72/17.72	126.13***
Fine Motor	83.02/19.58	109.86/18.73	84.25***
Gross Motor	77.31/18.13	106.05/22.02	95.28***

*** $\underline{p} < .001$.

APPENDIX G

TOTAL GROUP CORRELATION MATRIX

AMONG ALL VSC AND SM MEASURES

Table 8

Correlation Matrix Among all VSC and SM measures

	AGE	EDUC	FSIQ	PIQ	VIQ	TMAT	TMBT
AGE	1.000	-.005	.191	.075	.217	-.093	-.110
EDUC	-.005	1.000	.232	.128	.262	-.076	-.127
FSIQ	.191	.232	1.000	.831	.886	.254	.375
PIQ	.075	.128	.831	1.000	.489	.348	.403
VIQ	.217	.262	.886	.489	1.000	.136	.266
TMAT	-.093	-.076	.254	.348	.136	1.000	.546
TMBT	-.110	-.127	.375	.403	.266	.546	1.000
BCT	-.073	-.033	.222	.217	.173	.108	.149
BERR	.169	-.160	-.305	-.359	-.179	-.201	-.148
BLOC	-.163	-.007	.153	.277	.018	.253	.240

Table 8 (contd.)

	AGE	EDUC	FSIQ	PIQ	VIQ	TMAT	TMBT
BMEM	-.122	.019	.109	.257	-.040	.276	.189
FINE	-.166	-.014	.347	.397	.220	.394	.307
GROSS	-.257	-.036	.210	.250	.126	.265	.184
HVDTAVG	-.223	.029	.455	.572	.270	.300	.229
ALGO7	.119	.130	.120	.107	.108	-.046	-.140
AA	-.182	.095	.303	.207	.321	.192	.164
LCM	-.006	.136	.477	.281	.527	.082	.211
LNL	-.215	.187	.337	.243	.335	.143	.251
SR	-.362	.215	.451	.553	.287	.440	.415
NDI	-.243	-.039	.336	.386	.216	.409	.290

Table 8 (contd.)

	BCT	BERR	BLOC	BMEM	FINE	GROSS	HVDT AVG
AGE	-.073	.169	-.163	-.122	-.166	-.257	-.223
EDUC	-.033	-.160	-.007	.019	-.014	-.036	.029
FSIQ	.222	-.305	.153	.109	.347	.210	.455
PIQ	.217	-.359	.277	.257	.397	.250	.572
VIQ	.173	-.179	.018	-.040	.220	.126	.270
TMAT	.108	-.201	.253	.276	.394	.265	.300
TMBT	.149	-.148	.240	.189	.307	.184	.229
BCT	1.000	-.147	.181	.121	.148	.155	.202
BERR	-.147	1.000	-.222	-.264	-.242	-.163	-.427
BLOC	.181	-.222	1.000	.717	.247	.165	.326

Table 8 (contd.)

	BCT	BERR	BLOC	BMEM	FINE	GROSS	HVDT AVG
BMEM	.121	-.264	.717	1.000	.260	.201	.334
FINE	.148	-.242	.247	.260	1.000	.482	.320
GROSS	.155	-.163	.165	.201	.482	1.000	.291
HVDTAVG	.202	-.427	.326	.334	.320	.291	1.000
ALGO7	-.053	-.004	.016	.126	-.001	-.019	.008
AA	.173	-.255	.145	.118	.223	.123	.259
LCM	.158	-.080	.155	.131	.105	.034	.185
LNL	.145	-.212	.283	.145	.099	.096	.250
SR	.268	-.376	.476	.477	.427	.407	.566
NDI	.207	-.223	.246	.254	.829	.848	.358

Table 8 (contd.)

	ALGO7	AA	LCM	LNL	NDI
AGE	.119	-.182	-.006	-.215	-.243
EDUC	.130	.095	.136	.187	-.039
FSIQ	.120	.303	.477	.337	.336
PIQ	.107	.207	.281	.243	.386
VIQ	.108	.321	.527	.335	.216
TMAT	-.046	.192	.082	.143	.409
TMBT	-.140	.164	.211	.251	.290
BCT	-.053	.173	.158	.145	.207
BERR	-.004	-.255	-.080	-.212	-.223
BLOC	.016	.145	.155	.283	.246

Table 8 (contd.)

	ALGO7	AA	LCM	LNL	NDI
BMEM	.126	.118	.131	.145	.254
FINE	-.001	.223	.105	.099	.829
GROSS	-.019	.123	.034	.096	.848
HVDTAVG	.008	.259	.185	.250	.358
ALGO7	1.000	-.028	.154	-.080	-.018
AA	-.028	1.000	.263	.322	.209
LCM	.154	.263	1.000	.385	.114
LNL	-.080	.322	.385	1.000	.141
SR	-.074	.309	.281	.413	.475
NDI	-.018	.209	.114	.141	1.000

APPENDIX H

FORCED ENTRY DISCRIMINANT FUNCTION ANALYSIS OF

SEVEN GLOBAL FACTORS

Table 9

Classification Results for Multiple Discriminant Analysis (Forced Entry) Between Brain Damaged and Normal Controls on Seven Global Factor MDS Variables

Actual Group	n	Predicted Group Membership	
		Brain Damaged	Non-Brain-Damaged
Original			
Brain Damaged	137	113 (82.5%)	24 (17.5%)
Non-Brain-Damaged	64	10 (15.6%)	54 (84.4%)
Cross-Validated			
Brain Damaged	137	111 (81.0%)	26 (19.0%)
Non-Brain-Damaged	64	10 (15.6%)	54 (84.4%)

* 83.1% of original grouped cases correctly classified
* 82.1% of cross-validated grouped cases correctly classified

Table 10

Standardized Canonical Discriminant Function Coefficients for Forced Entry on Seven

Global Factor MDS Variables

Variable	Function 1
BCTTSCORE	.092
BVMGTE	.047
FSIQ	.373
HVDTAVG	.222
NDI	.562
TRAILSAT	.160
TRAILSBT	.018

Table 11

Pooled Within-Groups Correlations between Discriminating Variables and Standardized

Canonical Discriminant Functions for Forced Entry on Seven Global Factor MDS

Variables

Structure Matrix		Characteristics of Function
Variable	Coefficient	
NDI	.846	Eigenvalue: .886
FSIQ	.716	Canonical Correlation: .685
HVDTAVG	.644	Wilks' Lambda: .530
TRAILSAT	.561	Chi-Square: 124.001
TRAILSBT	.466	Significance: < .001
BCTTSCORE	.349	
BVMGTE	-.366	

APPENDIX I

STEPWISE DISCRIMINANT FUNCTION ANALYSIS OF

SEVEN GLOBAL FACTORS

Table 12

Classification Results for Multiple Discriminant Analysis (Stepwise) Between Brain

Damaged and Normal Controls on Seven Global Factor MDS Variables

Actual Group	n	Predicted Group Membership	
		Brain Damaged	Non-Brain-Damaged
Original			
Brain Damaged	137	118 (86.1%)	19 (13.9%)
Non-Brain-Damaged	64	13 (20.3%)	51 (79.7%)
Cross-Validated			
Brain Damaged	137	118 (86.1%)	19 (13.9%)
Non-Brain-Damaged	64	13 (20.3%)	51 (79.7%)

* 84.1% of original grouped cases correctly classified
* 84.1% of cross-validated grouped cases correctly classified

Table 13

Standardized Canonical Discriminant Function Coefficients for Stepwise Analysis on

Seven Global Factor MDS Variables

Variable	Function 1
FSIQ	.506
NDI	.709

Table 14

Pooled Within-Groups Correlations between Discriminating Variables and Standardized

Canonical Discriminant Functions for Stepwise Analysis on Seven Global Factor MDS

Variables

Structure Matrix		Characteristics of Function
Variable	Coefficient	
NDI	.879	Eigenvalue: .820
FSIQ	.744	Canonical Correlation: .671
HVDTAVG	.484	Wilks' Lambda: .549
TRAILSAT	.418	Chi-Square: 118.611
TRAILSBT	.396	Significance: < .001
BVMGTE	-.312	
BCTTSCORE	.259	

APPENDIX J

FORCED ENTRY DISCRIMINANT FUNCTION ANALYSIS OF

COMPREHENSIVE MDS MODEL

Table 15

Classification Results for Multiple Discriminant Analysis (Forced Entry) Between Brain
Damaged and Normal Controls on 15 MDS Variables

| | | Predicted Group Membership | |
Actual Group	n	Brain Damaged	Non-Brain-Damaged
Original			
Brain Damaged	137	125 (91.2%)	12 (8.8%)
Non-Brain-Damaged	64	9 (14.1%)	55 (85.9%)
Cross-Validated			
Brain Damaged	137	120 (87.6%)	17 (12.4%)
Non-Brain-Damaged	64	9 (14.1%)	55 (85.9%)

* 89.6% of original grouped cases correctly classified
* 87.1% of cross-validated grouped cases correctly classified

Table 16

Standardized Canonical Discriminant Function Coefficients for Forced Entry on 15 MDS
Variables

Variable	Function 1
BCTTSCORE	.028
HVDTAVG	.112
TRAILSAT	.180
TRAILSBT	-.111
BVMGTL	-.019
BVMGTM	.129
AA	.056
LCM	.304
LNL	.327
GROSS	.370
FINE	.185
PIQ	.030
VIQ	.133
ALGO7	-.250
SR	-.032

Table 17

Pooled Within-Groups Correlations between Discriminating Variables and Standardized

Canonical Discriminant Functions for Forced Entry on 15 MDS Variables

Structure Matrix		Characteristics of Function
Variable	Coefficient	
LNL	.623	Eigenvalue: 1.262
GROSS	.616	Canonical Correlation: .747
FINE	.579	Wilks' Lambda: .442
LCM	.544	Chi-Square: 156.348
HVDTAVG	.539	Significance: < .001
VIQ	.517	
PIQ	.512	
TRAILSAT	.470	
AA	.442	
TRAILSBT	.390	
BVMGTL	.383	
BVMGTM	.360	
SR	.360	
BCTTSCORE	.292	
ALGO7	-.199	

APPENDIX K

STEPWISE DISCRIMINANT FUNCTION ANALYSIS OF

COMPREHENSIVE MDS MODEL

Table 18

Classification Results for Multiple Discriminant Analysis (Stepwise) Between Brain

Damaged and Normal Controls on 15 MDS Variables

		Predicted Group Membership	
Actual Group	n	Brain Damaged	Non-Brain-Damaged
Original			
Brain Damaged	137	120 (87.6%)	17 (12.4%)
Non-Brain-Damaged	64	11 (17.2%)	53 (82.8%)
Cross-Validated			
Brain Damaged	137	119 (86.9%)	18 (13.1%)
Non-Brain-Damaged	64	11 (17.2%)	53 (82.8%)

* 86.1% of original grouped cases correctly classified
* 85.6% of cross-validated grouped cases correctly classified

Table 19

Standardized Canonical Discriminant Function Coefficients for Stepwise Analysis on 15

MDS Variables

Variable	Function 1
LCM	.358
LNL	.453
GROSS	.447
FINE	.320

Table 20

Pooled Within-Groups Correlations between Discriminating Variables and Standardized

Canonical Discriminant Functions for Stepwise Analysis on 15 MDS Variables

Structure Matrix		Characteristics of Function
Variable	Coefficient	
LNL	.665	Eigenvalue: 1.109
GROSS	.657	Canonical Correlation: .725
FINE	.618	Wilks' Lambda: .474
LCM	.581	Chi-Square: 146.998
VIQ	.467	Significance: < .001
PIQ	.449	
HVDTAVG	.412	
TRAILSBT	.370	
AA	.366	
TRAILSAT	.338	
BVMGTL	.336	
SR	.332	
BVMGTM	.286	
BCTTSCORE	.239	
ALGO7	.010	

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