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Clinical Applications of Neuropsychological Tests in the Diving Industry *

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I.

Introduction

Neuropsychology is broadly concerned with the measurement and description of the overt minifestations of brain dysfunction. It represents the product of both animal research and clinical observations of patients who have sustained brain damage of various etiologies including physical trauma, disease, and substance abuse.

Animal studies of the relation of various areas of the brain to external behavior have primarily involved two basic approaches: ablation, or removal of tissue from discrete areas of the brain, or stimulation of various regions of the brain and observation of the resulting behavior, if any. Both approaches have contributed knowledge on the localization of various brain functions. Analogous observations have been obtained from humans but from a case of opportunity rather than in a systematic fashion. If one seeks information on the effects of loss of function of a given area of the human brain, it becomes necessary to wait until a patient with injury to the area in question becomes available for study. Of course, in animal studies it has been possible to remove or manipulate quite discrete areas of brain tissue, whereas in humans the damage is rarely well localized and often is diffuse or multifocal and can only be confirmed or described at autopsy. Electrical or mechanical stimulation of discrete areas of the human brain have been possible during cortical surgery and cases where stimulating electrodes have been placed into the brain for control of epileptic activity.

Further complicating the study of human neuropsychology is the interdependence of various functions and the adaptability of the human brain.

As would be expected, given the complexity of the human brain and the relatively uncontrolled source of material for study, there remain a considerable number of questions and lack of agreement on the most appropriate and most sensitive ways to identify and localize the presence of brain damage. While techniques exist for the identification of gross physical changes, e.g. the electroencephalogram, X-rays and Computerized Axial Tomography (CAT) scans, these do not assess the degree of functional impairment, which is at least as important as the physical evidence.

The primary clinical applications of human neuropsychology remain in the areas of description and diagnosis of brain damage-related impairment of function, planning of a rehabilitation program and subsequent retesting to document degree of recovery. The techniques that are used vary from simple observation of an obvious behavioral deficit, to sophisticated measures of brain function involving complex behavioral tasks and studies of the electrical activity of the brain during sensory stimulation. Between these extremes are an almost endless variety of paper and pencil tasks which are being used as tests of brain function. The rationale for use of a test varies from logic, e.g., research suggests that damage to a given area of the brain should produce a deficit measurable by the test, to the purely empirical approach where a variety of tests are administered to brain damaged patients and the test results subsequently related to the location of brain damage as confirmed at autopsy.

From a clinical perspective, the latter approach is the most useful, since the primary concern is identifying and localizing the damage and its effect on behavioral function, whether or not research and logic suggest that such a relationship should exist. Of course, it is ultimately hoped that tests will be found such that both observation and logic will present a consistent result.

Probably the least equivocal signs of brain damage are those that are least dependent on the motivation and cooperation of the patient. For example, clear losses in sensory or motor function which cannot be attributed to peripheral nerve damage present few diagnostic problems. More difficult is the diagnosis of damage to an area of the brain concerned with more complex functions, e.g., abstract reasoning. This is because the function is less well localized, measurement of deficit is more difficult and the deficit may be due to personality or experience rather than, or in addition to, brain damage. Unfortunately, most presently available tests of complex brain function depend heavily on the experience and clinical judgment of the individual administering and scoring the test. It takes relatively little training and experience to identify a sensory or motor deficit. A totally different level of sophistication is necessary to evaluate a patient's memory function; memory function multiply determined, involving not only memory, per se, but also attention, concentration and motivation, among others.

Clearly, an important goal of neuropsychology is to develop a set of standardized assessment instuments which will provide both valid and reliable diagnostic information about brain damage in humans. How close achievement of that goal is, is equally at disagreement as is the question of which test or set of tests is of most diagnostic value. Fortunately, clinical neuropsychology is an expanding area and there is a continuous influx of new techniques to be validated. Of equal importance, increased awareness of the potential contributions of neuropsychology in the clinical arena contributes to increased access to the brain damaged patients necessary to validate any new method of assessment.

Reitan's revision of the Halstead neuropsychological test battery was selected for the present study because it is the most thoroughly standardized and documented of the various test batteries used for diagnosing the presence of brain damage in humans. There is certainly a lack of agreement on which of the available test batteries is the "best." However, few would argue that the Halstead-Reitan battery is not the most completely documented and validated now available.

The Neuropsychological Test Battery

Neuropsychological evaluations can range from a brief single test which has reasonable validity and reliability for identifying the presence or absence of brain damage, to a battery of tests each designed to assess a different aspect of brain function as well as providing an overall probability of the presence of brain damage. The Bender Visual-motor Gestalt test (Bender, 1939) is probably the most well known and most widely used example of the single tests for brain damage. The "Bender" consists of nine simple designs which the patient is asked to copy, one at a time, onto a blank piece of paper. There are a variety of scoring systems which define up to 106 different scorable parameters for the set of nine cards (Pascal & Suttell, 1941). Although primarily a test of simple visual-motor ability, the Bender has been suggested as useful for identifying brain damage by several studies (Brilliant & Gynther, 1963; Yates, 1966; Lachs, Harrow, Colbert, & Levine, 1970). A major disadvantage of any of the single brief tests for brain damage is the lack of comprehensive evaluation of brain functions. For this reason, various authors have developed batteries of individual tests which have been shown to, or are thought to, identify brain damage (Smith, 1975; Lezak, 1976). Many of these test batteries are quite flexible, with the particular set of tests used, depending on the judgment of the individual doing the testing. This, of course, makes the usefulness of the test highly dependent on the experience and expertise of the examiner. A more serious disadvantage is that these informal test batteries limit the possibility for accurate test-retest comparisons unless done by the same examiner with the same set of tests.

Unique among neuropsychological test batteries is that initiated by Halstead (1947) and modified by Reitan (undated). The result has been a set of tests of neuropsychological function which is highly standardized in terms of test composition, administration and scoring. This level of standardization has encouraged considerable research using the test battery (Reitan, 1955b; Goldstein, Deysack & Kleinknecht, 1973; Reitan & Davison, 1974), which has indicated a significant ability to identify individuals with brain damage-related impairment of function. Studies critical of the Halstead-Reitan test battery have generally focused on the slightly less accurate differentiation of brain damaged patients from psychiatric patients (Matthews, Shaw, & Kløve, 1966; Watson, Thomas, Anderson, & Felling, 1968; DeWolfe, Barrell, Becker, & Spaner, 1971), a weakness shared by all psychological and neuropsychological tests (Lezak, 1976, p.442).

The Halstead-Reitan Neuropsychological Test Battery as used in our study of U.S. Navy divers consisted of seven subtests which are used to calculate the Halstead Impairment Index and four additional tests which contribute additional information about location and probable history of the damage.

The following tests are used to compute the Impairment Index:

1. The Categories Test consists of the slide presentation of 208 stimulus figures and four response switches numbered one through four. The test is divided into seven subsets of stimulus figures. Within each subset, a single abstract concept relates each of the stimulus figures to a number from one through four. The patient's task is to abstract that concept and use it to obtain correct responses to as many of the stimulus figures in that subset as possible. The concepts to b- extracted include number, color, intensity, shape and location. This test calls forth a variety of abilities including attention, concentration, memory, complex concept formation and problem solving ability.

2. The Tactual Performance Test uses a modified Seguin-Goddard Form Board and requires the patient to fit a series of shapes into appropriate spaces while blindfolded. The test is repeated three times, first with the preferred hand, then non-preferred hand, and finally using both hands. At no time is the patient permitted to see the shapes or form board. Subsequently, the patient is asked to recall the shape and location of as many of the shapes as possible. Performance

is measured in terms of speed of placement under each of the three conditions, the number of shapes correctly recalled and the number of correctly recalled placements. The test is assumed to measure tactile form recognition, manual dexterity, kinesthesis, ability to visualize shape from factile information and memory.

3. The Rhythm Test is a measure of nonverbal auditory perception which requires the patient to indicate whether pairs of tone sequences are the same or different. The test is part of the Seashore Tests of Musical Talent and, in the present context, is assumed to measure sustained attention, auditory perception and auditory comparator functions.

4. The Speech Sounds Perception Test provides a measure of auditory acuity, requiring the patient to identify each of 60 spoken nonsense words. Response is indicated by selection of one of a set of four printed alternative words for each spoken word.

5. The Finger Tapping Test is a measure of simple motor speed of the right and left index fingers. The patient receives five consecutive 10-second trials with each index finger. The score for each hand is the average number of taps in 10 seconds. This test compares right-left motor speed and is useful in indicating generalized or lateralized loss of motor speed.

The preceding seven scores (number of correct responses for the Categories, Speech Sounds, and Rhythm tests, total elapsed time, number of shapes recalled and placement for the Tactual Performance Test and speed of tapping for the Finger Tapping Test) are used to calculate the Halstead Impairment Index. The Impairment Index is a summary score indicating the proportion of the seven subtest scores which exceed the normal limits for nonbrain damaged adults.

In addition to the seven scores comprising the Impairment Index, the following tests are also included.

1. The Wechsler Adult Intelligence Scale is an individually administered set of

eleven subtests measuring the patient's find of general information, common sense reasoning, abstract reasoning, mental arithmetic ability, immediate auditory memory, vocabulary, speed of visual-motor associative learning, perceptual-motor skill, nonverbal reasoning and recognition of logical sequence. The resulting pattern of subtest scores suggests relative areas of weakness which help to localize brain damage. In addition, the overall level of intellectual function suggests expected levels of performance on the other tests which, if not reached, indicate impairment.

2. Trail Making Tests, A and B. The Trails A test requires that the patient connect a series of 25 circled numbers as quickly as possible starting with the number one and continuing in numerical order until the number 25 is reached. Trail Making part B contains the numbers 1 through 13 and the letters A through L. The patient's task is to alternate numbers and letters in sequence (e.g., 1-A-2-B . . . 13-L). The times required to complete part A and part B constitute the scores for this test. The test is assumed to measure performance under time pressure and flexibility in shifting set between numerical and alphabetical series.

3. The Sensory-Perceptual examination is a series of tests designed to evaluate the intactness of sensory input and the ability to correctly perceive the source of that sensation. The tests include unilateral and bilateral auditory, visual and tactile stimulation including tests for suppression. The purpose of the examination is to identify losses in sensory function which can serve to localize brain damage.

4. The Aphasia Screening Test is a modification of the Halstead-Wepman (Halstead & Wepman, 1959) Aphasia Screening Test and is designed to determine the presence of both receptive and expressive language problems and related abilities such as anomia, acalculia, constructional apraxia and central departhria.

The total test battery requires approximately six to eight hours to administer, although more time may be required for patients with very severe impairment. As can be seen from the number and variety of tests administered, a great deal of information becomes available about a wide range of human abilities which are important for everyday functioning. Both the level and pattern of performance yield information which can help to localize the areas of the brain which might be involved and also can suggest nonorganic factors such as educational or cultural deprivation which might result in impairment unrelated to brain damage. Although the time involved in test administration may seem a disadvantage, the highly standardized nature of the procedures makes it possible, and even desirable, that the tests be administered by a well trained technical-level person and only the scoring and interpretation done by a clinician.

Relevance of the Neuropsychological Evaluation to Divers

Neuropsychological tests are useful in the context of diving for the same reasons that they are important in any case of brain damage. That is, diagnosis, treatment planning and evaluation of recovery of function. As a group, divers are exposed to a variety of conditions which increase the risk of central nervous system damage, the primary of which is decompression accidents. The effects of decompression accidents are well known and need not be discussed here, however, because of the statistical nature of decompression tables, individual differences in personnel and situational factors, exposure to hyperbaric situations carries the risk of unanticipated or unavoidable instances of decompression sickness or pulmonary embolism (Beckman, 1975). Prompt identification of the symptoms and application of appropriate treatment recompression schedules and associated medical therapy have generally been considered adequate to ameliorate symptoms and minimize any long-term effects (Goodman, 1966). It has also been assumed that central nervous system (CNS) symptoms of decompression sickness are largely confined to the spinal cord (Hallenbach et al., 1975) despite the fact that there is a lower probability of damage for spinal cord arterial cord emboli than for cerebral, cerebellar and brain stem arterial emboli (Kelly & Peters, 1975). The fact that major episodes of decompression sickness have been clearly shown to result in significant CNS impairment (Peters, Levin & Kelly, 1977; Levin, 1975; Rozsahegyi, 1959) emphasizes the need for a capability to identify neuropsychological deficits which may result from hyperbaric accidents. Impairment of immediate memory, visual-motor coordination, alertness and concentration as well as increased incidence of depression, irritability and anxiety found by Peters et al. (1977) in brain damaged divers have obvious consequences for the successful outcome of diving operations.

In addition, identification of these problems is of particular importance since the effects of borderline brain damage may only appear during episodes of stress or anxiety (Small, 1973). Thus, a deficit of minor proportions under normal circumstances may go undetected in a routine physical examination but under the stress of diving may become of sufficient magnitude to impair the individual's performance.

In our studies to date, we have completed neuropsychological evaluations on 20 normal Navy divers who have not experienced significant or frequent episodes of decompression sickness and a control group of 20 age, IQ, and rate-matched non-diving Navy personnel. Auditory brain stem, and auditory and visual cortical evoked responses, along with a clinical EEG, have also been obtained on a representative sample of these subjects. Longer latencies between waves I and V of the auditory brain stem response have been found but the significance, both statistically and physiologically, is unclear and more data are necessary. Thus far, there are no apparent differences between the divers and non-divers. Evidence of brain damage-related impairment of function was found in two control subjects. Subsequent examination of previously unknown medical histories disclosed chronic alcohol abuse in one and traumatic head injury in the other. There is also very clear evidence of mild increases in neuropsychological impairment with increasing age across subjects. This relationship is well known and further supports the validity of the present test battery.

We have recently completed testing a group of commercial and sports divers from the Hawaiian Islands in a collaborative study with the University of Hawaii. This group was treated for decompression accidents involving the CNS. Results of these evaluations will be compared to the previous baseline data collected on the normal Navy divers and non-diving Navy controls. Results of these data will also be compared to the standard neurological examinations to determine if the neuropsychological evaluations make a unique contribution to diagnosis, prognosis, or recovery/rehabilitation planning. If possible, follow-up testing will be attempted as a means of documenting recovery of function and effectiveness of treatment. Final analysis and interpretation of these data should be completed for presentation at the annual Undersea Medical Society meeting in May of this year.

The majority of injured divers tested by us and others have displayed spinal cord symptoms from inadequate decompression in the bounce diving mode. However, little, if any, neuropsychological data have been collected from divers experiencing decompression sickness in the saturation mode, although long-term saturation dives, such as the Aegir dive in Hawaii and others, have produced decompression sickness. The period of time under pressure was considerably longer than that which was used by the U. S. Navy to develop the saturation diving decompression tables, a fact that may have contributed to their increased incidence of decompression sickness.

There are several possible advantages of providing neuropsychological evaluation of working divers. The first is that of longitudinal monitoring of the functional abilities of the diver so that if the diver does become injured, there are baseline data to document the actual degree of impairment. Although a very controversial area, this baseline information can be of considerable importance to both the diver and his employer in the event apportionment of responsibility for job-related disability becomes a matter of contention. In addition, if a particularly susceptible individual begins to show signs of impairment, he can be protected from further exposure and subsequent risk, again protecting both the diver and his employer.

The use of neuropsychological test batteries in undersea medicine is of a relatively recent origin. These tests, together with brain stem auditory evoked responses and the EEG, may provide sensitive measures of the presence of neuropsychological impairment and brain damage, and should permit identification of areas of impairment or abnormal functions that are not obvious on routine physical examinations.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

(U) Neuropsychological tests are those designed to measure human abilities known to be affected by various types of brain damage. These tests have typically been used to measure impairment and document recovery in cases of organic brain syndrome due to such causes as head trauma, aging, cerebrovascular accidents, and drug or medication overdoses. Certain patterns of impaired test performance can suggest both location and extent of brain damage. While the usual neurological examinations and tests,

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e.g., EEG, CAT scan, etc., provide information on subcortical function and organic damage, respectively, neuropsychological tests indicate degree of impairment of cerebrocortical functions such as memory, concentration, judgment, and perceptual-motor skills. Knowledge of such impairments is of particular importance in divers since stress potentiates brain damage-related impairment of abilities. A diver who appears relatively normal at the surface may, under the physiological and psychological stress of a dive, exhibit impairment which could pose risk to himself or others. A second area of concern is the documentation of responsibility. Obtaining baseline neuropsychological data on an individual at the time of initial employment can establish whether signs of impaired function following a diving accident were pre-existing conditions or were incurred since employment. Finally, these tests are useful for identification of areas of impairment in planning rehabilitation therapy, documentation of progress during recovery, and estimation of ultimate recovery level.