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BRAIN DAMAGE, INFORMATION PROCESSING, AND DRIVER CAPABILITY

Final Report

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16. ABSTRACT

The overall goal of the this pilot research project was to initiate a collaborative effort with Phoenix Baptist Hospital for the study of the relationship between information-processing capabilities and driving performance in brain-damaged individuals. To this end, a microcomputer based research facility was established at the Hospital. This facility allowed the testing of patients on a battery of visual information processing tasks developed as part of a larger ADOT project (Lindholm et all., 1986). A Road Test Evaluation form was designed in collaboration with the Hospital's driving instructor and subsequently used to evaluate the patients' driving skills. Data from the neuropsychological tests administered by the Hospital staff were also included in the assessment.

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EXECUTIVE SUMMARY

Brain damage can impair cognitive and perceptual capacities, thereby interfering with the ability of the individual to safely operate a motor vehicle. Detection of such impairment can be difficult, and neither the patient nor his or her doctor may be aware of the existence or the extent of such problems. Even if they are aware of certain disabilities, they may not be aware that these disabilities have potentially serious consequences if the patient should drive. Certainly, a person with potentially dangerous impairments could appear completely normal to a driver license examiner. Thus, many individuals who, as a result of injury or disease, have seriously impaired information-processing capacities may continue to drive. At the same time, brain-damaged people with only minor and remedial disabilities may needlessly stop driving for fear that they are no longer competent. An informed public policy and a comprehensive evaluation and testing program are necessary if we are to protect the rights and safety of both brain-damaged individuals and the driving public.

Phoenix Baptist Hospital has established an Adaptive Driving Center for the evaluation and training of disabled drivers and potential drivers. Occupational therapists assess the physical capacities of the patient and provide on-the-road training and evaluation. They also administer certain tests which reflect perceptual and cognitive skills

that may be important for safe driving.

In order to adequately screen, advise, train and/or develop compensatory devices for individuals with perceptual or cognitive deficiencies, those abilities that are critical to the task of driving must be assessed. Adequate testing is not yet possible, however, because the capabilities necessary for safe driving have not been identified. Therefore, there is a great need for research in this area.

The overall goal of the this pilot research project was to initiate a collaborative effort with Phoenix Baptist Hospital for the study of the relationship between information-processing capabilities and driving performance in brain-damaged individuals. To this end, a microcomputer based research facility was established at the Hospital. This facility allowed us to test patients on a battery of visual information processing tasks developed as part of a larger ADOT project (Lindholm et al., 1986). A Road Test Evaluation Form was designed in collaboration with the Hospital's driving instructor and subsequently used to evaluate the patients' driving skills. Data from the neuropsychological tests administered by the Hospital staff were also included in our assessment.

A limited number of brain-damaged patients were available for testing during the tenure of this project. However, visual processing deficits, not apparent on the neuropsychological tests, were revealed by our task battery. Although evaluation of the ability of tasks of this type to predict driving problems must await a much larger data base, the results have been promising. The one person who was judged to not be a competent driver was found to suffer from frequent, brief (6 seconds to a minute or two) periods of sleep or seizure activity of which he was unaware. As a result of this finding, the patient is undergoing additional neurological assessment. Clearly, he should not attempt to drive at this time. Our findings with regard to this patient were fortuitous; his impairment would have been apparent on any number of tasks with limited sensory input and discretely spaced trials. Nonetheless, these finding do argue for the importance of extensive and varied assessment of brain-damaged individuals who wish to drive. Only further research can delimit the nature and scope of testing necessary to identify persons with processing disabilities that preclude safe driving.

There are numerous causes of brain damage, and it can afflict young and old alike. However, cerebrovascular accidents and progressive neurological diseases are clearly more prevelant among the elderly. As the population ages, the need for information regarding the capacities necessary for safe driving and the availability of adequate evaluation instruments will become more critical. This information will not be acquired quickly or easily. A sustained and flexible research effort is needed if we are to meet the challenge posed by the brain-damaged driver.

It is recommended that ADOT continue to support research in this area. It is also recommended that the various committees appointed to set policy and to make decisions regarding who should be licensed should include both cognitive experimental psychologists and neuropsychologists. With adequate information from a patient's neurologist conerning the locus and extent of damage, assessment of questionable applicants with current neuropsychological test batteries would be a very useful, although not conclusive, screening procedure. These tests, however, should be administered and the results interpreted by a person with extensive training in the perceptual and cognitive consequences of brain damage.

INTRODUCTION

Background

Brain damage can impair motor and information processing (perceptual and cognitive) functions that are important for safe driving. Motor impairments, such as localized paralysis or muscular weakness, are not difficult to detect and often can be compensated for by vehicle modifications. (For example, a car can be equipped with hand rather than foot controls for the accelerator and brake.) The problems are much greater for information processing deficits. In order to adequately advise, train, and/or develop compensatory devices for individuals with such deficits, it would be necessary to assess driving-relevant information processing abilities. Appropriate testing is not possible at this time, however, because the capacities necessary for safe driving have not been identified. There is thus a great need for research in this area.

Evidence that information processing capabilities in normal adults are related to traffic accident history has been found in several recent experiments. Fergenson (1971) selected four groups of subjects, matched in driving experience, who differed in their driving records during the previous three years. The subjects were given a simple reaction time task, in which they were required to push a button whenever a red light appeared, and a choice reaction time task, in which they were required to push a different button for each of three lights that could appear. The difference between a subject's simple and choice reaction time was taken as a measure of decision time. Fergenson found that decision time was associated with accident history but not violation history. Drivers who had both high accident rates and high violation rates had the longest decision times; drivers who had had no accidents but several violations had the shortest decision times. Treat et al. (1977) also found a positive relationship between decision time (again, the difference between simple and choice reaction time) and accident involvement.

For a group of professional bus drivers, Kahneman et al. (1973) found a relationship between accident rate and performance on a task thought to measure auditory selective attention. Mihal and Barrett (1976) found that performance on a similar task as well as measures of "field dependence" were related to the accident rates of commercial drivers.

Sivak and his colleagues (Sivak et al., 1981) at the Highway Safety Research Institute, University of Michigan, investigated the effects of brain damage on certain perceptual/cognitive skills and on performance in two different types of driving situations. They used a variety of paper and pencil tests which assessed skills they expected to be important to driving performance and which have been found, in clinical settings, to reveal deficits in brain-damaged individuals. They also tested visual acuity, stereodepth, and choice reaction time. (The subject had to indicate which of 2 numbers was flashed.) Their subjects included 23 with brain damage, 8 with spinal-cord damage, and 10 without known central nervous system damage. They found that the brain-damaged people performed significantly less well than those without brain damage on most of the perceptual/cognitive and driving tests.

In a driver training study with handicapped people, Bardach (1971) found that those persons who were difficult to train were all left hemiplegics, who suffer from damage to the right cerebral hemisphere. Bardach reported that the left hemiplegics showed "inadequate scanning of the environment with consequent poor planning, inability to shift according to the changing demands of the driving task, distractibility, poor judgment, and confusion" (p. 331). In contrast, the verbal impairments that tend to accompany right hemiplegia did not appear to be critical to the task of driving. Similarly, Golper et al. (1980) found that a rehabilitation team's assessment of the driving skills of a group of individuals who had suffered brain damage was most strongly associated with their visual processing deficiencies, not with their linguistic impairment.

Phoenix Baptist Hospital's Adaptive Driving Center

The Phoenix Baptist Hospital Adaptive Driving Center offers evaluation and training to disabled and/or brain injured people who would like to drive or who are concerned about their ability to drive. The Center is operated by the

Hospital' sOccupational Therapy Department in cooperation with the Arizona Department of Economic Security's Department of Rehabilitation.

The hospital staff administers a number of tests designed to assess relevant sensory and motor capacities and certain perceptual/cognitive abilities. The latter neuropsychological tests were chosen because they appear to reflect skills needed for driving and because they have proved useful in clinical tests of brain damage. An occupational therapist, who is a certified driving instructor, provides on-the-road training and evaluation.

Objectives of the Research

The general objectives of this pilot research project were to establish a laboratory at Phoenix Baptist Hospital and to initiate a study which would increase our knowledge concerning the relationship between visual processing capabilities and driving performance. The specific objectives of the project were to (a) examine the interrelationships amoung various measures of information processing in a group of brain-damaged individuals, (b) compare the information processing capacities of the brain-damaged individuals with those of a group of control subjects who were tested as part of another ADOT project; and (c) examine the relationship, for brain-damaged individuals, between information processing performance and driving performance.

Research Approach

The research project covered in this report included the following activities:

1. Development of a Road Test Evaluation Form for the driving instructor/trainer to use in her evaluations.

2. Setting up of a microcomputer based research facility in the hospital.

3. Testing brain-damaged patients on six information processing tasks.

4. Reducing, analyzing, and reporting the data from (a) neuropsychological tests administered by the hospital staff, (b) the information processing tasks, and (c) the on-the-road evaluations.

METHOD

Neuropsychological Tests

As part of the initial client evaluation for the Adaptive Driving Center, the occupational therapist/driving instructor administerd six neuropsychological assessment tests:

Attention Diagnostic Method

The Attention Diagnostic Method (ADM) was developed by Rutten (Rutten and Block, 1975). It involves searching an array of randomly ordered numerals and reading them in ascending order. It is thought to reflect an individual's ability to maintain attention on a given task. Rutten and Block report driver accident data from insurance company and industrial records which suggest that, if scores on ADM I and ADM II are considered together with the age of the individual, the test may be sensitive to the propensity of an individual to have accidents. A modified version of ADM I was administered to the people who participated in this study.

For this test, the Arabic numerals 10 to 59 were arranged in random order, in 10 lines of 5 numerals each, on a 9 in. x 7 in. card. The background color for the numerals was black. The first five lines of numerals were red, yellow, green, white and blue, respectively; the second five lines repeated this sequence of colors. The instructions were to read the numbers in numerical order, and to state the color of the row in which each number was found. Although no mention of speed was made in the instructions, both the number of errors and the number of seconds to complete the task were measured. Rutten and Block found that task time was a more predictive and reliable measure than number of errors. Since our cases made few errors, we report results only for the time measure.

Digit Span

The digit span test is from the Wechsler Adult Intelligence Scale-Revised (WAIS-R) (Wechsler, 1981). Subjects are presented with lists of digits which they are to repeat in either forward or backward order. Performance on this test is often held to reflect auditory short-term memory capacity (Miller, 1956; Parkinson, Lindholm & Inman, 1981). In the neuropsychological literature, however, it is also referred to as a test of attention (Lezak, 1976, p. 210; Matarazzo, 1972, p. 205).

For the digits forward part of the test, lists of random digits are read at a rate of one digit per second. The subject is instructed to repeat the digits when the list is done. The test begins with a list of three digits. List length is incremented by one digit every two trials. Testing ends when two lists of the same length are repeated incorrectly. One point is given for each list repeated in the correct order.

The digits backward test is identical to the digits forward test except that testing begins with lists of 2 digits and the instructions are to repeat the list in reverse order. The final score is the sum of points awarded for digits forward and backward.

Picture Arrangement

The Picture Arrangement test is from the WAIS-R. It uses cartoon pictures that tell a story when placed in the correct order. According to Matarazzo (1972, pp. 208-209), the Picture Arrangement test measures the ability to "comprehend and size up a total situation," since the subject must grasp the idea of the story the pictures are intended to relate in order to arrange the pictures correctly.

On each trial a unique set of pictures is placed before the subject in a standard scrambled order and the subject is instructed to rearrange the pictures so that they tell a story. Points are awarded when correct arrangement of the pictures is completed within a prescribed time limit (60 to 120 seconds, depending on item difficulty).

Mazes

The Mazes test is from the Wechsler Intelligence Scale for Children-Revised (WISC-R) (Wechsler, 1974). An individual's performance on a maze test is thought to provide information concerning his or her "foresight" and planning ability.

The stimulus for each trial is a maze composed of a number of concentric squares with gaps and connecting lines such that alleys and blinds are formed. Only one pathway can be traced from the center to the outside of the maze without doubling back or crossing lines. There is a representation of a person in the center of each maze. The instructions to the subject are to help the person get out of the maze by drawing a path out from the center of the maze without crossing walls. Points are earned by correct completion of a path within prescribed time limits.

Spatial Relations

The Spatial Relations test is from the Woodcock-Johnston Psychoeducational Battery (Woodcock and Johnston, 1977). It involves visual search and the mental rotation and matching of geometric shapes.

On each trial the subject is shown a two dimensional geometric form which is dissected by one or more lines. To the left of this target form are a number of smaller forms, some of which match the shapes created by the dissecting lines in the target. The small forms on the left may be in the same orientation as in the target or they may be rotated 90, 180, or 270 degrees. The remaining forms to the left of the target are foils which do not match pieces of the target. The subject is instructed to identify the shapes on the left that make up the shape on the right. The chosen shapes are indicated by reciting the letters printed underneath them. Points are awarded for correct responses given within prescribed time limits.

Trail Making Test

The Trail Making Test is from the Halstead-Reitan battery (Reitan & Davison, 1974). It is similar to the Attention Diagnostic Method in that it involves locating, in numerical order, randomly arranged numerals. It is thought to assess "visual conceptual and visuomotor tracking" ability (Lezak, 1976, p. 429). Only Part A of the test was administered.

Part A consists of twenty-five 1/2 - in. diameter circles distributed haphazardly over an 8-1/2 in. x 11 in. sheet of paper. The circles are numbered from 1 to 25, such that the numbering has no apparent relationship to the location of the circles. The subject is instructed to use a pencil to connect the circles as quickly as possible, beginning with the number one and proceeding in numerical sequence. The score is the number of seconds required to complete the task. Any errors made during the task are immediately pointed out by the examiner and time to correct errors is included in the total time.

Information Processing Tasks

The six tasks described in this section were developed as part of ADOT Project No. HPR-1-23(196), "Visual Processing and Driving Safety."

Apparatus

A Digital Equipment Company PDT 11/150 microcomputer was programmed to present the stimuli and record the response time and accuracy data for these tasks. The stimuli were presented on a Hewlett-Packard 2648A Graphics Terminal. The observers viewed the graphics screen from a distance of approximately 68 cm. This distance was maintained by an opaque, black, open-ended rectangular box which was affixed to the front of an enclosure for the terminal. Wearing their normal corrective lenses, observers rested their foreheads against a plastic rim attached to the open end of the box. Behind the rim a pair of oversized lenses, mounted at their focal distance (66.7 cm) from the screen, placed the display optically at an infinite distance from the observer. The horizontal positions of the lenses were adjusted for each subject.

The subjects were seated in a modified dentist's chair which included an hydraulic lift that allowed the vertical position of the subject to be adjusted over a wide range. An adjustable headrest was used to stabilize the subject's head. The arms of the chair were designed so that they could hold one or two response switches. Subjects with normal use of their upper extremities were tested with one switch mounted on each arm. Two switches were mounted on one arm for subjects with use of only one hand.

Multidimensional Stimuli

The stimulus patterns for the simple reaction time, perceptual matching, and focusing tasks were constructed by combining two levels of each of three different dimensions of pattern information: spatial frequency, form, and orientation (see Figure 1). These stimuli were chosen because the dimensions themselves are of interest and because similarity, which affects stimulus processing time and accuracy, is frequently defined in terms of the number of shared attributes.

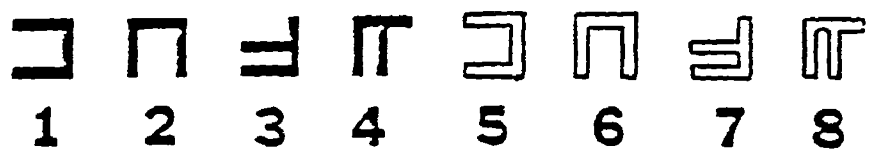

Figure 1. Multidimensional stimuli.

On each trial in these tasks, the stimulus was displayed until the subject responded, or for 3 seconds. If the subject failed to respond in 3 seconds, a "nonresponse" was recorded and that trial was repeated at a later time.

Simple Reaction Time

In a simple reaction time (RT) task subjects are directed to respond to the onset of a stimulus. A minimum of processing is required, in that the subject need only detect the stimulus and execute a response. Stimulus dependent differences in reaction time indicate that stimulus attributes differentially affect detection latencies. The subject's average reaction time provides an estimate of his or her basic information processing and response speeds.

In the simple reaction time task used in this study, each of the 8 patterns in Figure 1 was presented to each subject 20 times, for a total of 160 trials. The first 32 trials were considered practice. Since both response buttons were used in the other information processing tasks, subjects were directed (via a message on the display) to switch response buttons every 16 trials. The order of stimulus presentation was random with the restriction that each of the 8 stimulus patterns be presented once in each set of 8 trials and that each pattern be presented once as the first trial after a hand switch. Subjects were instructed to respond as quickly as possible to stimulus onset.

Two measures of task performance were calculated. First, the subject's median RT for each target in each block was determined. The mean of the logarithms of these values was taken as an index of the subject's overall "response time." The major stimulus effect for this task involves the spatial frequency dimension. The 60 normal adults tested as part of ADOT Project No. HPR-1-23(196) responded more quickly to Patterns 1 to 4 than to Patterns 5 to 8. The difference in the mean log medians for these two sets of patterns constituted the "stimulus effect" measure for this task.

Perceptual Matching

In a perceptual matching task two patterns are presented on each trial and the subject must judge whether they are the same or different. This task involves encoding, comparison decision, and response processes. Reflecting the increased processing demands, response times in this type of task are appreciably longer than in a simple reaction time task.

In the perceptual matching task used in this study, all of the 8 possible "same" pairs and 56 possible "different" pairs which can be constructed from the patterns shown in Figure 1 were used as stimuli. Three blocks of 112 trials were presented. The first block was considered practice. Each block of 112 trials consisted of one instance of each "different" pair and seven instances of each "same" pair. The order of stimulus presentation was random with the restriction that each pattern was presented once as part of a "same" pair and once as the left member of a "different" pair in each subblock of 16 trials. Subjects were instructed to respond by pressing the right button when the two patterns were identical and with the left button when they were different. They were encouraged to respond as quickly as possible without making errors.

Two measures of performance were calculated. The log median correct RTs for the eight possible "same" pairs were averaged over blocks to give an overall measure of "response time." The "stimulus effect" was the difference between correct "same" response times (means of the logs of the median RTs) for Patterns 2 (for which RTs are fastest) and 8 (for which RTs are slowest).

Focusing

In a focusing task, one pattern is presented on each trial and the subject responds positively to a predesignated "target" pattern and negatively to all other patterns. This task differs from the perceptual matching task in that only one pattern is encoded on a trial and, more importantly, the comparison is between the stimulus pattern and an internal respresentation of the target pattern, held in memory.

The focusing task in the present battery consisted of two separate focusing conditions. In both conditions subjects were instructed to press the right button when the target was presented and the left button for all other patterns, as quickly as possible without making errors. Feedback was given to ensure that the target pattern was not forgotten: If the subject made an error, the message "Error, the target is" appeared on the display followed by the target pattern.

In Focusing I, each of the 8 stimulus patterns served as a target for 14 consecutive trials in each of 3 blocks of 112 trials. The first block was considered practice. During each set of 14 trials the target was presented 7 times and each of the nontargets was presented once. The order in which the patterns served as the target was controlled to ensure that successive targets were maximally different and that targets composed of both levels of each attribute were presented equally often in the first and second halves of a block.

In Focusing II, a pair of patterns served as the target stimuli for a set of 12 consecutive trials in each of 2 blocks of 144 trials. The first block was considered practice. The 12 target pairs consisted of all possible (i.e., 4) examplars of 3 types of pairs: 1) the 2 patterns differed only in spatial frequency; 2) the 2 patterns differed only in shape; and 3) the 2 patterns differed only in orientation. During the 12 trials associated with a particular target pair, each of the targets was presented 3 times and each of the nontargets was presented once.

The focusing tasks had a clear memory component, making both error and response time data of interest. The total number of errors was determined for each of the focusing tasks.

For Focusing I, the subject's "response time" was derived from the correct "different" RTs. Median RTs were determined for each of the seven types of pattern difference: spatial frequency; form; orientation; spatial frequency and form; spatial frequency and orientation; form and orientation; and spatial frequency, form, and orientation. For an overall "response time" measure, the log median RTs were averaged over blocks and type of difference. The "stimulus effect" for Focusing I was the difference between the log response times when the target and stimulus differed on only one dimension and when they differed on all three dimensions.

For Focusing II the reponse time measures were based on the correct "same" RT data. A median RT was computed for each pattern for each pair in which it served as a target. The overall "response time" measure was the mean of the logs of these values. The "stimulus effect" was determined by subtracting the mean log median RT when spatial frequency was irrelevant (which results in relatively fast RTs) from the mean of the log median RTs for the other two types of pairs (form or orientation irrelevant).

Unidimensional Stimuli

Form similarity can also be determined by the magnitude of the difference between two stimuli on a single dimension or attribute. The effects of this type of similarity were explored in two experiments. Each of these experiments employed a forced-choice discrimination paradigm. The stimulus patterns consisted of two vertical lines (see Figure 2). The longer of the lines appeared equally often as the left and right sides of the pattern. The subject's task was to indicate, via a button press, the relative position of the longer line.

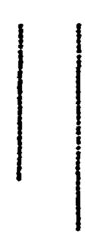

Figure 2. Target stimulus.

On each trial a small fixation square appeared for 250 msec, beginning 500 msec before target onset. This "warning" stimulus served to alert the subject and to specify the screen location of the ensuing target.

Length Discrimination

In this experiment the shorter of the two lines varied in length such that the difference in the lengths of the two lines ranged from approximately .3 mm (1 pixel) to approximately 10 mm (10 pixels). When viewed from a distance of 67 cm, .3 mm subtends a visual angle of approximately 1.5 arc minutes, whereas 10 mm corresponds to a visual angle of approximately 52 are minutes.

Lines differing by 10 pixels (the easiest discrimination) were presented for 1 raster scan during the first 24 of 54 practice trials. The 1 scan presentation produced a very low intensity stimulus and was used to insure that subjects did not suffer from ocular pathology that severely reduced the light reaching the retina. The remaining 30 practice trails consisted of 3 trials at each of the levels of discrimination difficulty. These practice trials, as well as the test trials, were displayed until the subject responded, or for 3 seconds.

Two test blocks of 80 trials each were presented. Each block of trials consisted of 8 presentations of each of the 10 differences in line length, 4 with the long line on the left and 4 with the long line on the right. Order of presentation was random with the restriction that each possible stimulus was presented once in each block of 20 trials.

Subjects were instructed to press the button on the side of the longer line, as quickly as possible without making errors. They were told to guess if they could not resolve the difference. If the subject failed to respond within 3 seconds, a "nonresponse" was recorded and the next trial was presented. Any stimulus to which the subject failed to respond was subsequently repeated.

Three measures of task performance were determined. The median correct RT for each level of discrimination difficulty and side of the longer line was computed for each block. The average of the logs of these values for the five easiest dsicrimination levels provided a measure of "response time." The difference between this value and the mean of the log medians for the two most difficult discrimination levels provided a measure of the "stimulus effect." The total number of discrimination errors was also determined ("errors").

Backward Masking

The reaction time measure employed in the preceding information processing tasks is assumed to represent the minimum amount of time a person needs to perform the required mental operations. However, performance is rarely error free. In many experiments these errors do not occur because the subject can not perform the task correctly (e.g., identify the stimulus), but because he or she fails to take enough time to do so. The percentage of errors increases if instructions emphasize speed and decreases if instructions emphasize accuracy. Moreover, individuals often differ in the "speed-accuracy" criteria they set in response to a given set of instructions.

An alternative method of assessing the duration of mental operations is to measure response accuracy when processing time is limited. Information about a stimulus persists in the nervous system long after stimulus offset, however, and processing time cannot be controlled by simply limiting stimulus presentation time. One procedure that is believed to restrict the time available for processing a stimulus is to follow its presentation by the presentation of a second stimulus. This second stimulus is called a "mask." "Backward Masking" occurs when perception of a target stimulus is impaired by the presentation of the second (masking) stimulus. The degree of masking is a function of the time between the onset of the target and the onset of the mask. This interval is referred to as the "stimulus onset asynchrony" (SOA). The SOA necessary to avoid masking is thought to be an index of the time needed to process the target stimulus.

In the backward masking task used in this research, the patterns with a 10 pixel difference in line length (see Figure 2) were used as target stimuli. The form of the mask is presented in Figure 3.

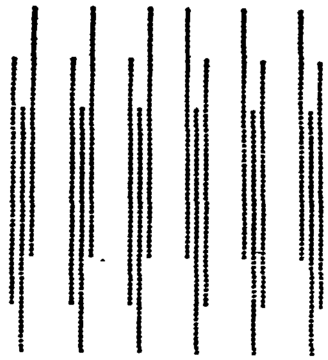

Figure 3. Masking stimulus.

The Hewlett-Packard terminal is a raster scan device with a refresh rate of 60 Hz and a very fast P4 phosphor (which decays to 10% in 60 sec). Target and mask stimuli were built and stored with the display off and then presented on successive scans, in precise alignment. The SOA was controlled by varying the number of raster scans separating target and mask onsets.

Two independent estimates of the SOA to evade masking were determined simultaneously. There were 70 practice trails prior to the test trial blocks. The first 32 trials presented SOA's from 333 msec (20 scans) to 217 msec (13 scans), in descending order. The next 54 practice trials started with an SOA of 200 msec (12 scans). Subsequent practice SOAs were determined by an adaptive rule: If an error occurred on a trial, the SOA was increased by 1 scan on the next trial. Three successive correct responses for a given SOA caused the SOA for the next trial to be decreased by 1 scan.

Three test blocks of 96 trials (+ 6 practice) were presented. The SOA for a given estimate was determined by an adaptive rule which converges on 84.1% accuracy: If an error occurred on a trial, the next longer SOA was presented on the following trial. Four correct responses in succession for a given SOA caused the next shorter SOA to be presented on the following trial.

Restrictions on the random sequence were employed to balance the frequencies of trials for the two estimates and for the two locations of the longer line.

The dependent measure for the backward masking task was the log of the median of the "peak" and "valley" SOAs. (A "peak" is an SOA for which the subject is correct four times in succession immediately following an error on a shorter SOA. A "valley" is an SOA at which an error is made immediately following a run of at least four correct responses.)

Road Test

Subjects were taken on an extensive road test as part of their initial evaluation at the Adaptive Driving Center, and on all subsequent visits. All subjects drove the same full-sized American sedan, which had been modified for handicapped

ROAD TEST EVALUATION FORM

Driver's Name:______________________________ Date:______

Instructor's Name:______________________________

(3)= Good (2)= Fair (1)= Poor

Familiarity with driving cockpit:

_____ a) how everything works
_____ b) where items are located

Right and left turn:

_____ a) position
_____ b) recovery

Speed control:

_____ a) constancy
_____ b) within posted limits

Space control:

_____ a) cushioning space
_____ b) stopping distance
_____ c) lane position
_____ d) lane choice

Awareness of environment:

_____ a) head turns
_____ b) frequency of eye movements
_____ c) awareness of traffic information
_____ d) ability to describe driving actions

Decision making:

_____ a) independence
_____ b) quality

(+)= too much (O)= OK (-)= too little

_____ Speed in turns
_____ Overall speed
_____ Brake press

Figure 4. Road Test evaluation form.

people. For the initial evaluation, subjects were required to drive on residential streets in Phoenix. If their driving performance on residential streets was adequate, city, rural and expressway driving were also included in the session. At least two road test evaluations were obtained for each subject, with the number of road sessions determined by the instructor/trainer who rode with the patient and filled out the Road Test Evaluation Form (Figure 4) at the end of each driving session.

Except for the three items at the end of the evaluation form, all ratings were on a three point scale, with 3 indicating good performance in a category and 1 indicating poor performance. The final three rating categories related to speed and brake pressure. The instructor gave a rating of "too much," "too little, " or "OK" for these items.

A summary of considerations which went into the ratings for each category is given below.

Familiarity with Driving Cockpit

Items a, "how everything works," and b, "where items are located," are somewhat redundant. A score of less than 3 indicated that the subject either attempted to use a control inappropriately (e.g., attempted to accelerate prior to engaging a driving gear), or asked where a common cockpit control (e.g., the gear shift) was located.

Right and Left Turn

"Position" refers to where the subject began and ended turns, and "recovery" was based on the whether or not the turn was completed with under- or over- correction.

Speed Control

A good "constancy" rating indicated that acceleration to speed was smooth and moderate and that there were not large fluctuations in speed irrelevant to road conditions. Under ordinary road conditions, driving within ± 5 miles per hour of the posted limit was considered driving "within posted limits."

Space Control

Proper "cushioning space" (following distance) was determined by using the "2 second rule": If the subject followed another car such that at least 2 seconds elapsed between the time the leading car passed any given point and the time the subject's car passed the same point, cushioning space was considered adequate. The 2 second rule was explained to the subject prior to the beginning of the road test.

"Stopping distance" scores were based on where the vehicle stopped in relation to other vehicles and landmarks. Stopping inappropriate distances on either side of traffic control indicators or crosswalks resulted in reduction of this score.

"Lane position" scores were decremented if the subject weaved excessively or tended to consistently drive too far to either side of a lane. "Lane choice" scores were based on whether (a) traffic control signs were attended to in lane selection and (b) the appropriate lane was moved to sufficiently in advance of turns.

Awareness of Environment

Subjects were expected to make "head turns" (a) to check traffic prior to making turns or lane changes; (b) when approaching uncontrolled intersections; and (c) prior to proceeding into controlled intersections following a stop. Failure to make appropriate head turns resulted in a reduced rating.

"Frequency of eye movements" ratings were based primarily on whether or not the subject checked the mirrors with sufficient frequency. "Awareness of traffic information" ratings were based on the subject's response to traffic indicators (e.g.,lane designation and warning signs). "Ability to describe driving actions" ratings reflected the quality of the subject's verbal responses to questions about what actions would be appropriate in various driving situations.

Decision Making

Good ratings for "independence" were given if the subject reacted to driving situations without consulting with, or requiring prompts from, the driving instructor. Good ratings for "quality" were given if the subject's reactions to driving situations were deemed appropriate by the instructor.

Turn Speed

Speed during turns was rated as "too much" if the tires squealed or the car was judged to be going too fast for adequate control. "Too little" speed generally reflected inappropriate stopping during turns.

Overall Speed

Overall speed was rated as "too much" if it was either too fast for traffic and road conditions or more than five miles over the speed limit. "Too little" speed ratings were given if, in the opinion of the instructor, the subject's slowness impeded traffic or created a hazard.

Brake Pressure

"Too much" brake pressure indicated hard stopping and "too little" brake pressure indicated excessively long stopping distances.

RESULTS

Data Analysis

Neuropsychological Tests

The subjects' scores on each neuropsychological test were converted to *z*-scores. A *z*-score is computed by the formula

$$z = (X - \bar{X})/s$$

where X is the subject's score on the test, $\bar{X}$ is the mean score from the test's standardization sample, and s is the standard deviation of the same sample. For most of the tests administered as part of this study, the standardization sample consisted of a large number of adults in their 20's and 30's.

A *z*-score shows the relative status of a score in a distribution and facilitates comparisons across tests. A *z*-score of zero indicates performance equal to the mean performance of persons in the standardization sample. If the test scores for the standardization sample approximate a normal distribution, as is typically the case, roughly 95% of the scores will fall between $\pm$ 2 *z*. For the purposes of this report, *z*-scores less than -2.0 will be considered to be abnormally low.

Information Processing Tasks

As described in the Method section, a subject's performance on each of the first five tasks was described by measures of overall response time and the "stimulus effect." For the focusing and length discrimination tasks, error rate was also determined. Performance on the backward masking task was represented by a measure of the SOA ncessary to evade masking.

Each of these scores was converted to a _z_-score with respect to the combined sample of 20 young (19 to 27 years) and 20 middle-aged (35 to 52 years) subjects tested on these tasks as part of ADOT Project No. HPR-1-23(196), "Visual Processing and Driving Safety." Although computation of the standard scores allows comparisons of performance across tests and individuals, the exact values of the _z_-scores should be viewed with caution. A sample of 40 people is insufficiently large to provide a truly adequate reference group, and the subjects tested were not a random sample of persons of their age groups.

Low _z_-scores on these tasks indicated that response times and SOAs were long, stimulus effects were large, and error rates were high.

Road Test

In order to provide a summary of the road test results, a total score was computed. First, we converted the rating for each item to a score between 0 and 1: The minimum rating ("1," "too much," or "too little") was assigned a score of 0, and the maximum rating ("3" or "ok") was assigned a score of 1; a rating of "2" on the 3-point scale was assigned a score of 1/2. Second, we multiplied the item scores by the

Table 1. Weights for the Scoring of the Road Test Evaluations

Item Description	Weight
Familiarity with Driving Cockpit	
How everything works	1.0
Where items are located	1.0
Right and Left Turn	
Position	0.5
Recovery	1.0
Speed Control	
Constancy	1.0
Within posted limits	1.0
Space Control	
Cushioning space	1.0
Stopping distance	1.0
Lane position	1.0
Lane choice	1.0
Awareness of Environment	
Head turns	1.5
Frequency of eye movements	1.0
Awareness of traffic info	1.0
Ability to describe actions	0.5
Decision Making	
Independence	1.5
Judgement	2.0
Speed in turns	1.0
Overall speed	0.5
Brake pressure	0.5

weights shown in Table 1, in an attempt to account for differences in item variance and perceived importance for driving safety. (Inspection of the data indicated that the driving instructor always assigned the maximum rating for some items on the test; her ratings for other items varied from subject to subject and from day to day. We gave low weights to items with little variance.) Third, we summed these weighted scores and converted that sum to a percentage.

Subject Performance

Case S.C.

At the time of initial evaluation at the Adaptive Driving Center, S.C., a 25-year-old woman, was 230 days posttrauma. She received the injury in a traffic accident and was comatose for approximately one month. Following the coma, she had experienced memory problems (such as being unable to recall addresses and phone numbers), but these complaints were minor at the time of testing. She had also been unable to read for some period of time; she read with great deliberation at the time of the evaluation. She had no hearing complaints. Her visual acuity, with corrective lenses, was within normal limits. Depth, color and peripheral visual perception also all tested within normal limits.

S.C. had completed 10th grade and was employed as a bartender prior to the accident.

Neuropsychological Tests. S.C.'s scores on the neuropsychological tests are presented in Figure 5. Her performance on the Attention Diagnostic test suggests an attentional deficit. In addition to taking almost double the average amount of time required to complete this task, S.C. made two errors. Roughly 99.8 % of persons her age in the standardization sample showed better performance. However, the stimuli used for patient testing were a degraded photograph of the stimuli used for establishing the norms. Whereas S.C.'s performance is definitely below average, it may not be as extreme with respect to normal adults as the *z*-score suggests.

In contrast to the results with the Attention Diagnostic Method, her performance on the Trail Making Test, which is also thought to reflect attentional deficits, was above average. Because S.C. is in the age group from which the standardization sample for this test (adults 20 to 39 years) was drawn, and because there were no substantial deviations from the standard method of administration, there is no reason to suspect that her score on this test is misleading.

The remaining test thought to be sensitive to attentional deficits is the Digit Span test, for which her performance was within normal limits. Her difficulty with the Attention Diagnostic Method may warrant further investigation, but the scores on the Digit Span and Trail Making Tests do not suggest a general attentional deficit.

Her scores on the Picture Arrangement and Spatial

Relations tests were in the average range and suggest normal comprehension and spatial perception. Her score on the Mazes test was low but still within the normal range and suggests adequate foresight.

Information Processing Tasks. S.C.'s scores on the information processing tasks are shown in Figure 6. Her performance on the simple reaction time task was average. Although her response times for the matching, focusing, and discrimination tasks were relatively long, they were within normal limits. Her performance on the backward masking task was also low normal. She was not highly sensitive to stimulus parameters and her error rates were normal. Taken together, these results suggest a relatively, but not abnormally, slow processing speed for a person of her age.

Road Test. Two driving evaluations, on consecutive days, were obtained for S.C. (see Figure 7). On the first day she scored 84 percent. She was marked down for driving too fast both in general and during turns. She had a tendency to tailgate. Braking was too abrupt. All other categories were rated "good." On the second day she corrected all the inadequacies noted on the first day and received a perfect score.

Relationship between performance measures. With one exception, S.C.'s scores on the neuropsychological tests and the information processing tasks indicated normal functioning. These findings were consistent with the driving instructor's evaluation of her driving performance.

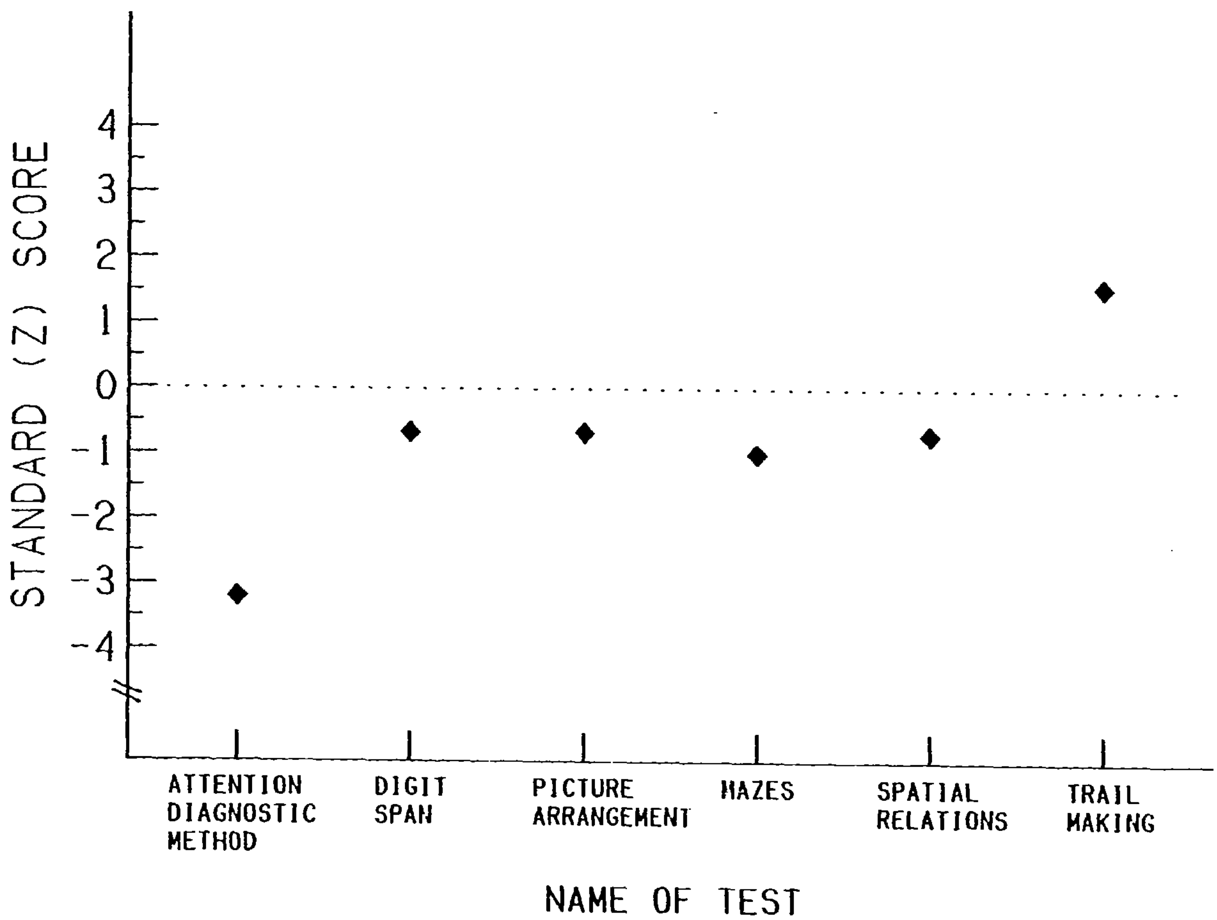

Figure 5. Neuropsychological test performance of S.C.

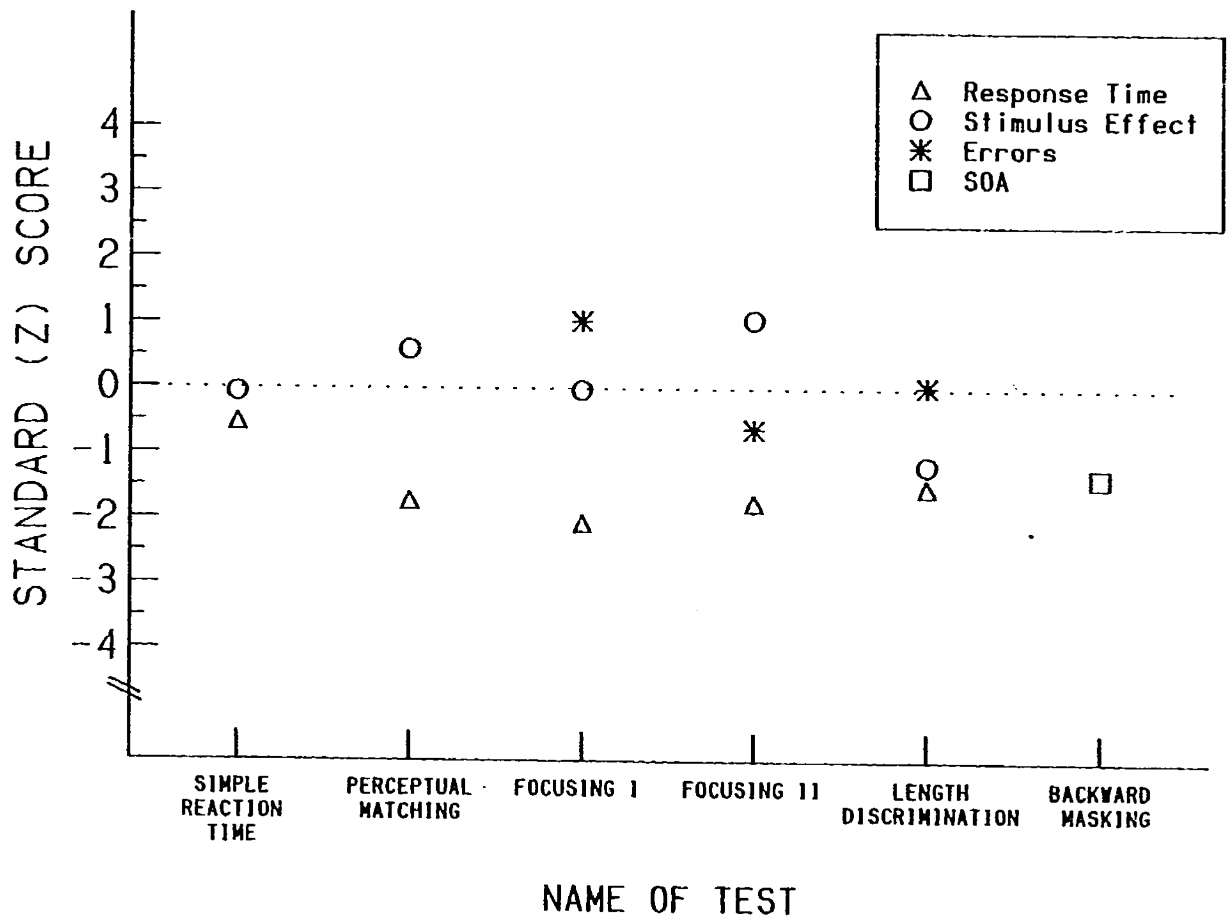

Figure 6. Information processing task performance for S.C.

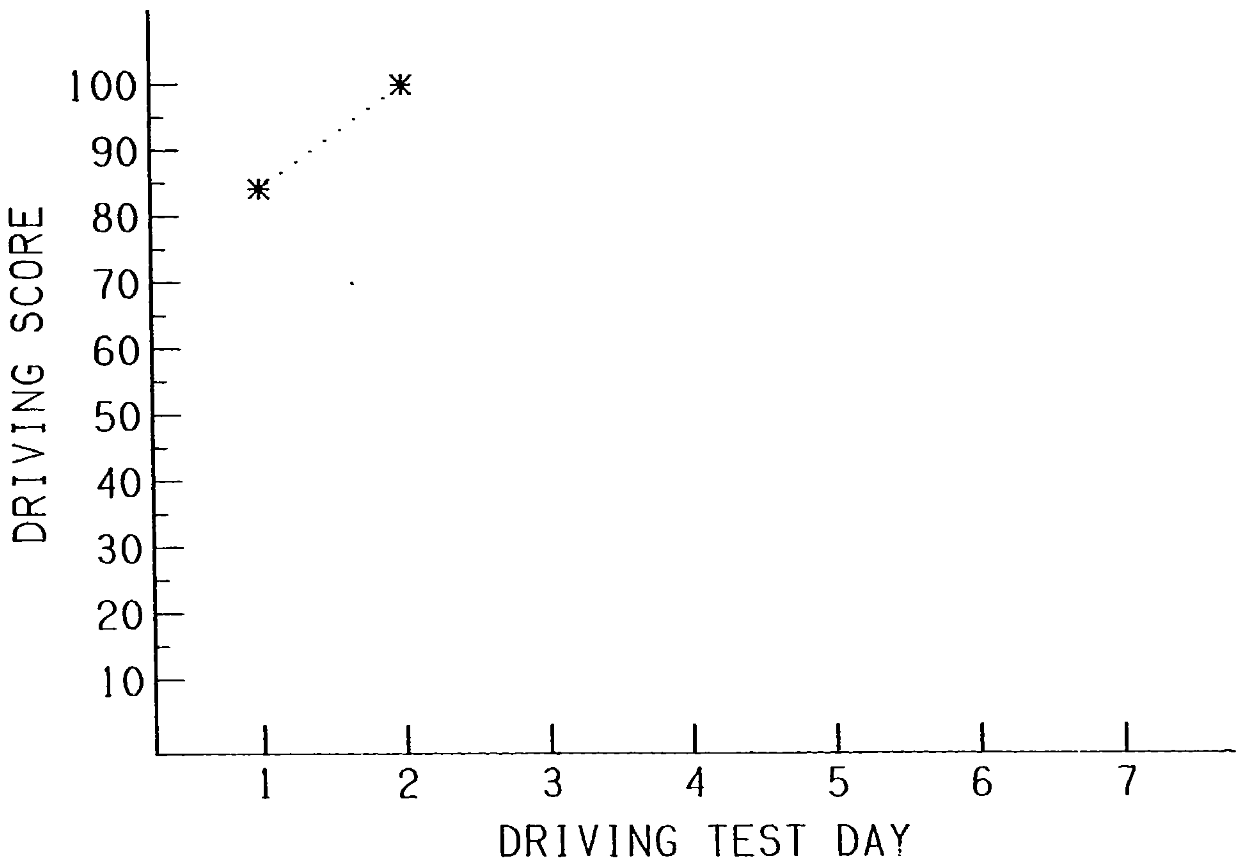

Figure 7. Road Test performance for S.C.

Case I.D.

I.D. was a 62-year-old male at the time of initial evaluation. Approximately three months prior to his initial evaluation, he had had a stroke following surgery to correct partial bilateral carotid occlusions. The primary damage was to the right hemisphere. He was stronger on the right side of his body than on the left. He had a cut in his left visual field, but his central field vision was spared. He said he did not sense the absence of left visual field information and sometimes bumped into things on his left ("left neglect"). However, he expressed understanding of this handicap and compensated by frequently turning to the left. Visual acuity, binocular depth, and color perception were within normal limits. His only visual handicap was the left scotoma. He compensated for a moderate hearing loss by watching the lips of persons speaking to him.

I.D. had a 10th grade education and was self employed with a refrigeration business prior to the stroke.

Neuropsychological Tests. I.D. performed poorly on the majority of neuropsychological tests (see Figure 8). His scores were exceptionally low on both the Attention Diagnostic Method and Trail Making Test, which could indicate an attentional deficit. The presence of left neglect could, however, also account for these findings. Persons with left neglect will search the right portions of visual stimuli without awareness that they are ignoring the left portions. In addition, the Trail Making Test is extremely age sensitive

(Davies, 1968). Relative to his age group, his performance on this test was poor but not extremely so.

I.D.'s poor performance on the Picture Arrangement, Spatial Relations and Mazes tests may also be attributable to normal age-related decline and/or spatial neglect. His performance was within the normal range and about average for his age on the Digit Span test, which does not require visual perception but is sensitive to attentional deficits. (Digit Span is subject to decline with normal aging.)

Information Processing Tasks. I.D.'s scores on the information processing tasks are presented in Figure 9. His performance was normal on the simple reaction time task. Although he showed a relatively large stimulus effect (negative *z*-score) on the perceptual matching task, this measure is age sensitive, and he was clearly normal with respect to his age group. His response time and stimulus effect scores were normal for Focusing I, but he made an abnormally large number of errors. Interpretation of this finding is difficult. It is unlikely to represent a memory deficit since he made few errors in Focusing II, which had similar memory requirements. Most of his errors were to "different" stimuli and may have represented a bias to respond "same." He demonstrated no problems with Focusing II which was presented following Focusing I.

On the length discrimination task, I.D.'s error rate was highly deviant and his response time was relatively long. His errors were confined primarily to the three hardest discriminations when the longer line was on the right side. In other words, when the lengths of the lines were similar he indicated that the longer line was on the left, regardless of its position. This was not an acuity problem since the differences are easily distinguishable with normal acuity. It is not clear how this result relates to the "left neglect" previously reported, but it does suggest a visual processing problem.

I.D.'s performance was also poor on the backward masking task. The long SOA he needed to escape masking may have been due, in part, to normal age-related decline, as this task is age sensitive. In addition, he showed a tendency to indicate that the long line was on the left rather than on the right, even though only the maximum difference in line length was used in this task. This tendency probably affected the SOA estimate.

Road Test. Driving assessments were obtained for I.D. on three days within an eight day period (see Figure 10). On the first day, he had difficulty finding and using some controls; his speed was erratic but generally too slow; he did not look to his left as often as was deemed necessary; he did not utilize his mirrors adequately; he relied on the instructor for decisions concerning lane selection; and he tended to ignore traffic sign information. His overall score was 62 %.

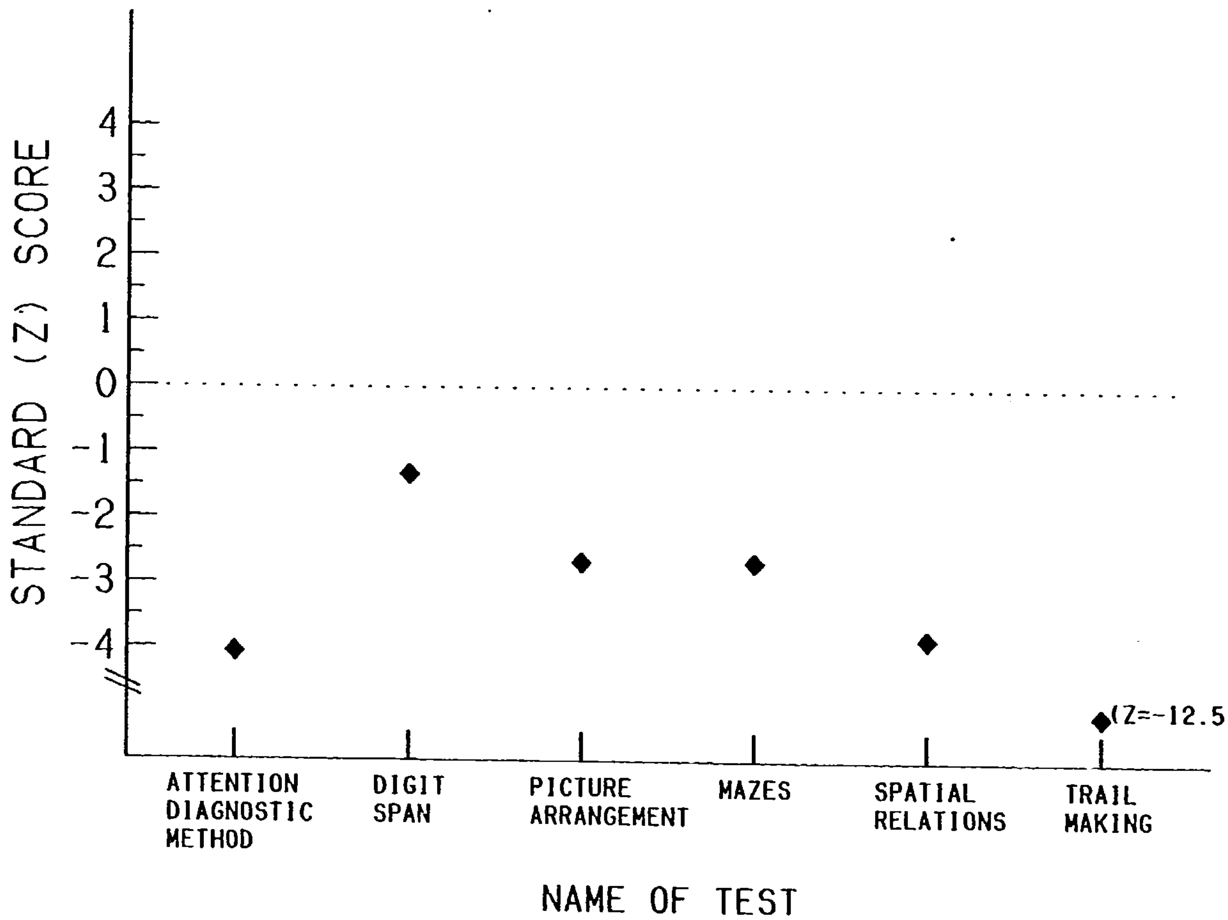

Figure 8. Neuropsychological test performance for I.D.

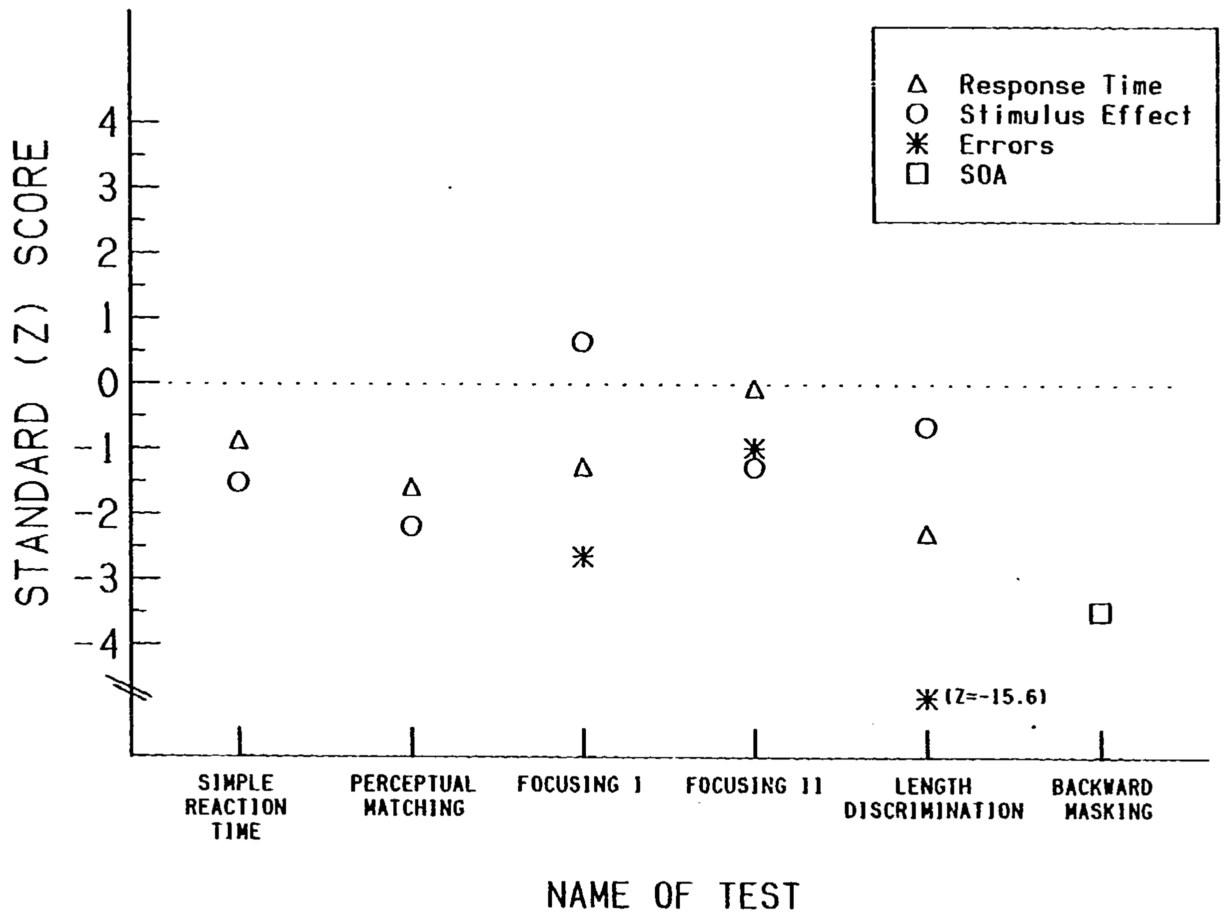

Figure 9. Information processing task performance for I.D.

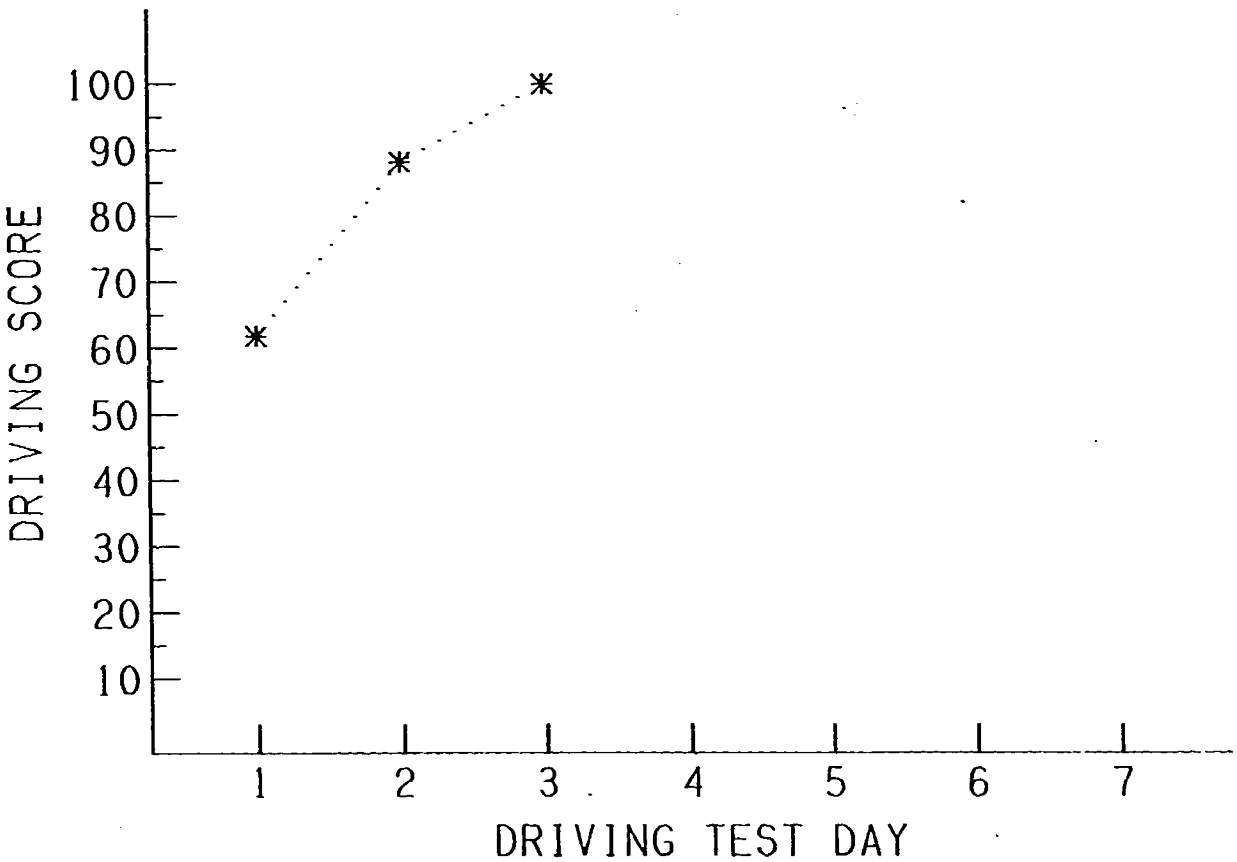

Figure 10. Road Test performance for I.D.

On the second day, he showed considerable improvement. He lost points for putting the car in gear before attempting to start the engine. He still relied too heavily on the judgement of the instructor. In all other respects his performance was good, including adequate attention to information on his left. On his third session, his performance was "good" in all areas.

Relationship between performance measures. I.D. performed poorly on several of the neuropsychological tests and information processing tasks, suggesting that he has perceptual/cognitive deficits which could interfere with his ability to drive safely. The driving instructor, however, found him to be a competent driver. Subsequent follow-up would be necessary to resolve the discrepancy.

Case H.D.

At the time of initial evaluation, H.D. was a 39-year-old female. She had had a cerebrovascular accident in the left middle cerebral artery distribution ten months prior to the evaluation. She had shown aphasia and alexia in the days following the stroke but her speech and reading abilities were close to normal at the time of evaluation: She read somewhat slowly and showed some word finding difficulty. She showed residual right hemiparesis. She used a brace on her right ankle and used a four legged cane for walking more than short distances. Although she had regained some use of her right hand she now wrote with her left hand (she was previously right handed). Visual acuity, binocular depth and color perception all tested within normal limits. She had no hearing complaints.

H.D. had a high school education and had been employed as a yard foreman.

Neuropsychological Tests. As shown in Figure 11, H.D. peformed poorly on several of the neuropsychological tests. Her poor performance on the Digit Span test could have resulted from either a short-term memory deficit or her verbal disabilities. Her low score on the Trail Making Test probably resulted from its motor requirements since her performance on the Attention Diagnostic Method, which also requires number registration and attention, was low but within normal limits. Her score on the Spatial Relations Test was also low but within normal limits. The requirement for letter name responses, rather than any deficit in the perceptual skills central to performance on this task, could have reduced her score on this test. Her scores were average on the two tests (Mazes and Picture Arrangement) which require no verbal skills.

Information Processing Tasks. H.D.'s scores on the information processing tasks are presented in Figure 12. Her performance was normal for all tasks and measures with the exception of two stimulus effect measures: On the perceptual matching task, the time she needed to decide that two patterns were the same was highly dependent upon the attributes of the patterns. As these stimuli are quite "letter like," this finding may be related to her residual reading problems. On the length discrimination task, the increase in her response latency with discrimination difficulty was abnormally large, suggesting either extreme cautiousness or some type of acuity problem.

The tasks in which she showed abnormally large stimulus effects involved the simultaneous, side-by-side presentation of patterns. In contrast, her stimulus effect scores were normal in the two focusing tasks in which only one pattern was presented per trial. This difference may have been critical. The data suggest but do not consistently indicate that she has a problem encoding or discriminating certain stimuli. Further study would be necessary to establish the nature and significance of these findings.

Road Test. H.D. received seven assessments of driving skill over a 21 day period (see Figure 13). On the first day she showed some difficulty in all areas except those under the "Awareness of Environment" heading. She tended to drive too fast and stop too hard. She had some difficulty with the controls, primarily because she was learning to use her left foot to operate the foot pedals. She was reluctant to make decisions on her own. She did not allow adequate following distance and did not control the vehicle well in turns.

On her second evaluation she showed considerable improvement. Although she no longer drove too fast she still had difficulty maintaining a constant speed. Her control of the vehicle through turns was still less than adequate. She

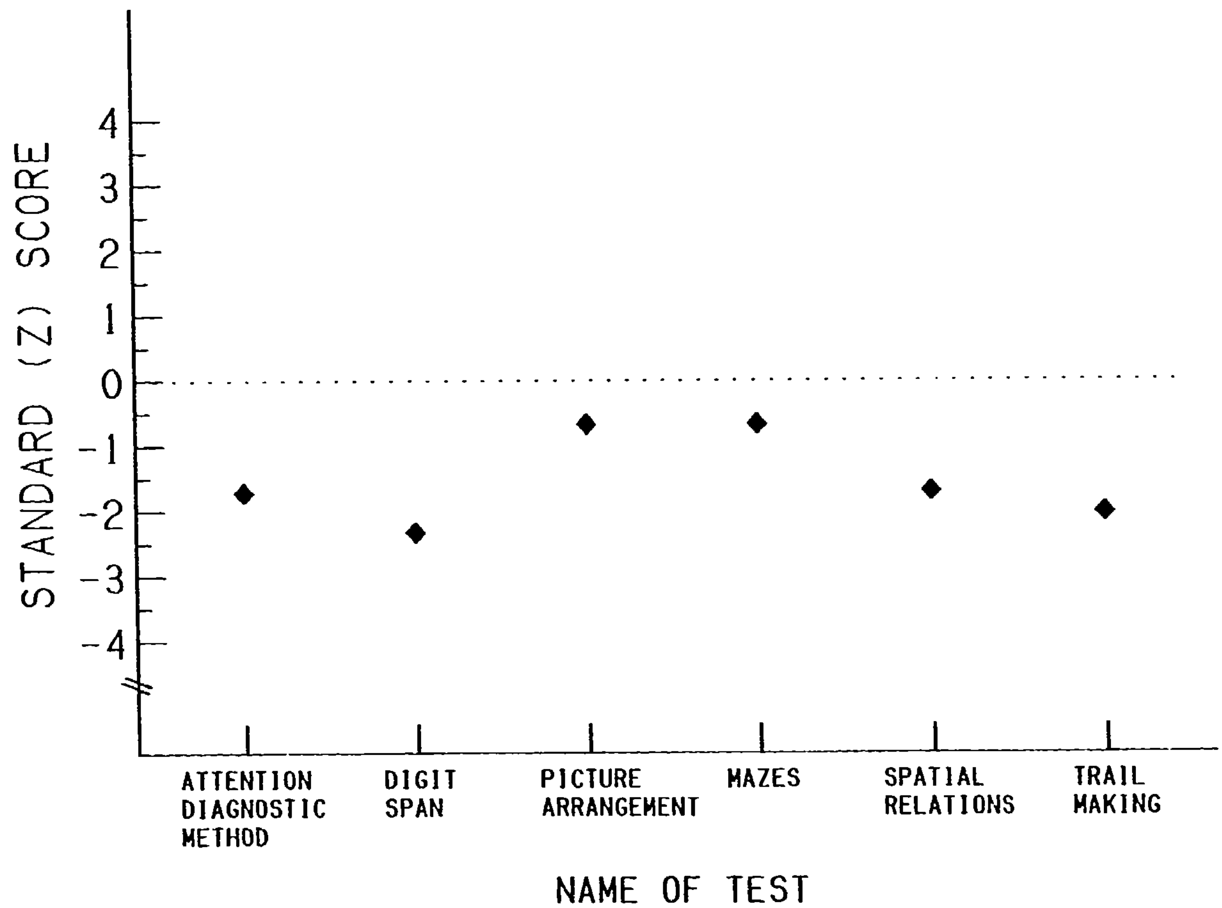

Figure 11: Neuropsychological test performance for H.D.

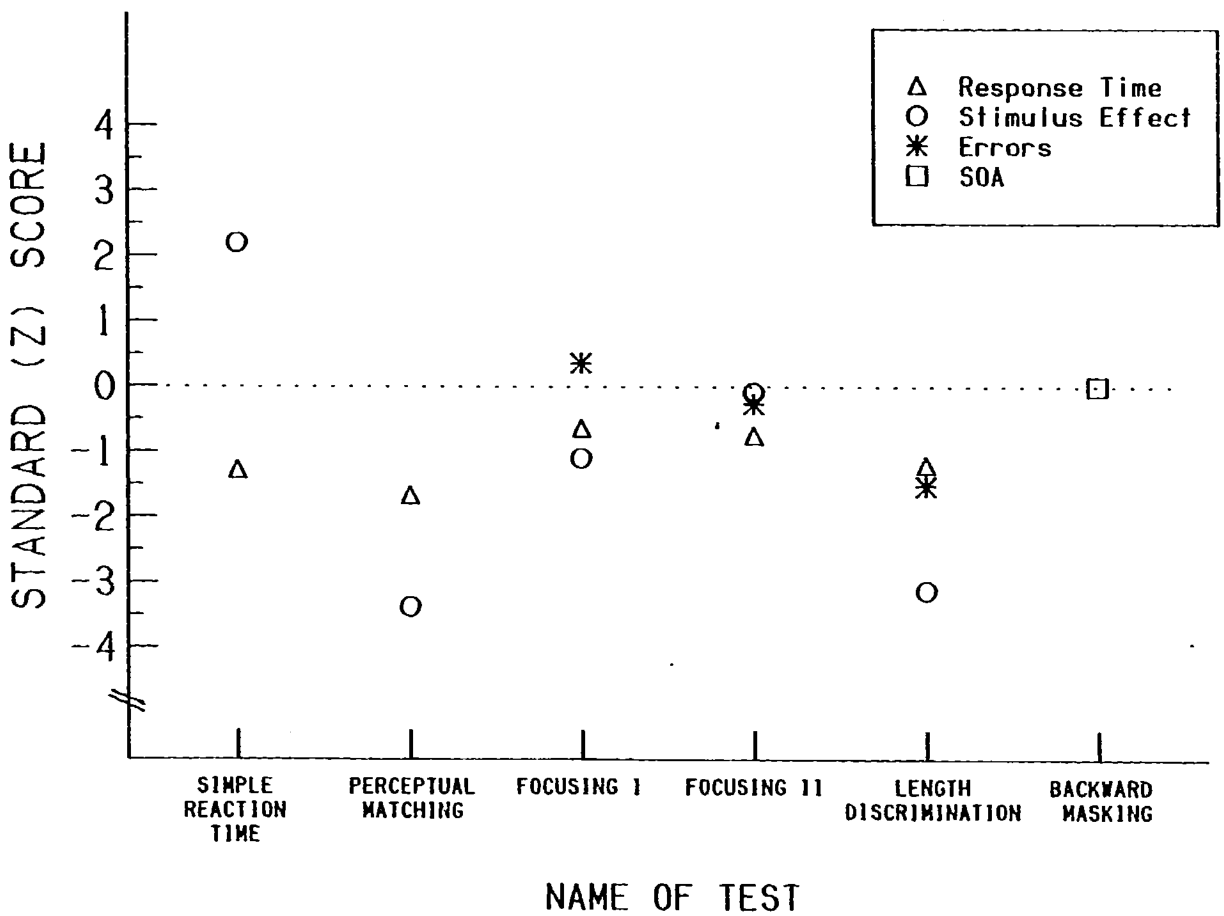

Figure 12: Information processing task performance for H.D.

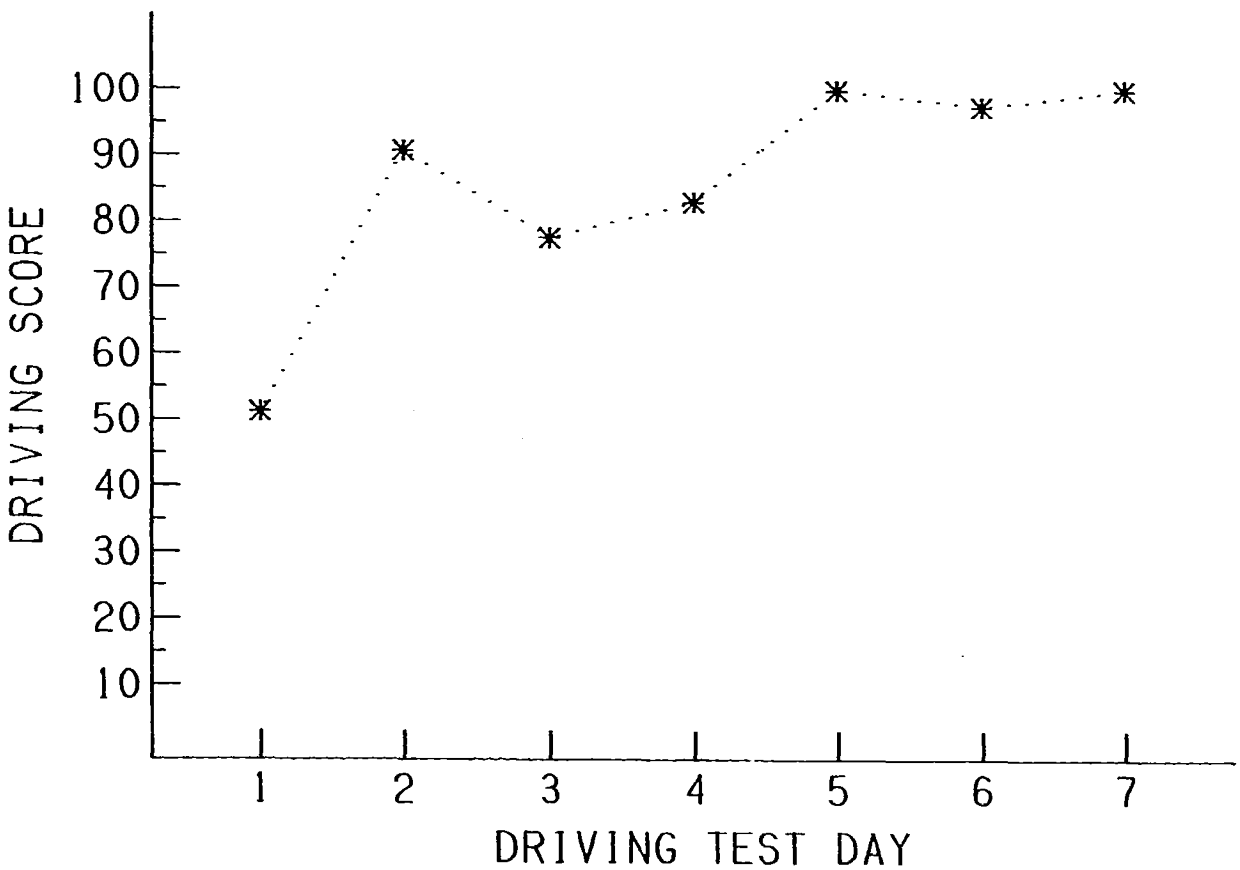

Figure 13. Road Test performance for H.D.

did not consistently show good lane selection. Her performance was acceptable in other respects.

On the third evaluation, her control during turns improved, but she reverted to tailgating and hard braking. She again relied too much on the judgement of the instructor. On the fourth evaluation, she continued to rely on the instructor's judgement and had difficulty in recovery from turns. She was still braking too hard.

H.D.'s performance was perfect on the last two evaluation days. On the last day she also successfully completed a road test given by an ADOT Motor Vehicle Division (MVD) examiner.

Relationship between performance measures. H.D.'s performance was normal on the majority of neuropsychological tests and information processing tasks. These tests provided no data to seriously question her ability to drive safely. The basis of her poor Digit Span performance could not be established (i.e., memory or verbal deficit) and the significance of the two abnormal stimulus effect scores was questionable. These findings are in basic agreement with the driving instructor's judgement that she was capable of driving safely.

Case U.T.

At the time of initial evaluation, U.T. was a 21-year-old male. He had undergone two surgeries for ruptured intracranial aneurysms approximately 3 1/2 years prior to his evaluation. Following the second surgery, he had remained comatose for approximately two months. At the time of testing, he had some paresis in his left leg and spoke somewhat slowly. His visual acuity and color perception tested within normal limits. Binocular depth perception was poor and outside normal limits. Peripheral vision was normal. He had no hearing complaints.

U.T. did not complete high school because of his medical difficulties. He had attended a special school for the handicapped. At the time of the evaluation he was managing a small storage rental business with the aid of his family.

Neuropsychological Tests. As shown in Figure 14, U.T. scored within the normal range on all six tests, the only one of our five cases to do so. His scores were low, but within normal limits, on the Mazes and Trail Making Test. His remaining scores were about average. The two tests on which his scores were relatively low are the only two test which require manipulation of a pencil. It is possible that his performance on these tests may have been affected by motor slowness.

Information Processing Tasks. U.T.'s scores on the information processing tasks are presented in Figure 15. His response times were very long for both the simple reaction time and the perceptual matching tasks. His error rates were high on the focusing tasks (on which his response times were average) and extremely deviant on the length discrimination task. The estimate of the SOA needed to escape masking was abnormally long. His sensitivity to stimulus factors was within normal limits.

Like I.D., U.T.'s errors on the length discrimination task were for the more difficult discriminations and involved responding "left" when the longer line was on the right. Moreover, his errors on the backward masking task, and thus the SOA estimate, were almost exclusively due to left response errors. Finally, his errors on the focusing tasks were primarily to "same" pairs -- that is, he responded with his left hand when he should have responded with his right.

Although these data indicate slow and inaccurate information processing, they do not tell the entire story. In contrast to the neuropsychological tests, the information processing tasks involved relatively long periods (5 to 8 min) during which the primary source of stimulation was the visual display (much like the driving task when one is the sole occupant of the car). With the exception of the day on which the focusing tasks were presented, U.T.'s behavior during testing was characterized by repeated, brief (6 sec to 2 min) periods during which he ceased responding and lost muscle tonus. The onsets of these periods were typically preceded by abnormally long response times. Repeated queries indicated that U.T. was unaware of the existence of this behavior.

<u>Road Test</u>. The initial Road Test performance of U.T. was very poor (see Figure 16). Although he returned for repeated training and evaluation sessions (eight times), he showed little improvement. He was the only case for which a

recommendation against driving was made.

During the initial evaluation, U.T.'s behavior reflected an understanding of the car's controls and instruments, but his driving performance was deficient in every category. Following extensive training, he showed "good" positioning and recovery for turns, and he was rated "good" in his ability to describe appropriate driving actions. However, his performace was still less than satisfactory performance in the remaining categories. The instructor consistently commented that U.T. needed verbal prompting. It was her impression that he did not exercise good judgement.

Relationship between performance measures. U.T. performed normally on all of the neuropsychological tests. In contrast, the information processing tasks revealed major processing problems. Not only were his scores below normal, but the input and attentional demands of the tasks revealed a hitherto unknown tendency to lose consciousness. Prior to receiving this information, the driving instructor had decided that U.T. needed more instruction than she could provide. She suggested that U.T. practice driving with his fiancee and return to the Hospital for additional work in a few months. Based on our findings, all of the parties involved agreed that this would not be wise, and U.T. was referred for additional neurological assessment. (It seems likely to us that his apparent lack of awareness of traffic information and the poor quality of his decisions represented periods when he had stopped processing information.)

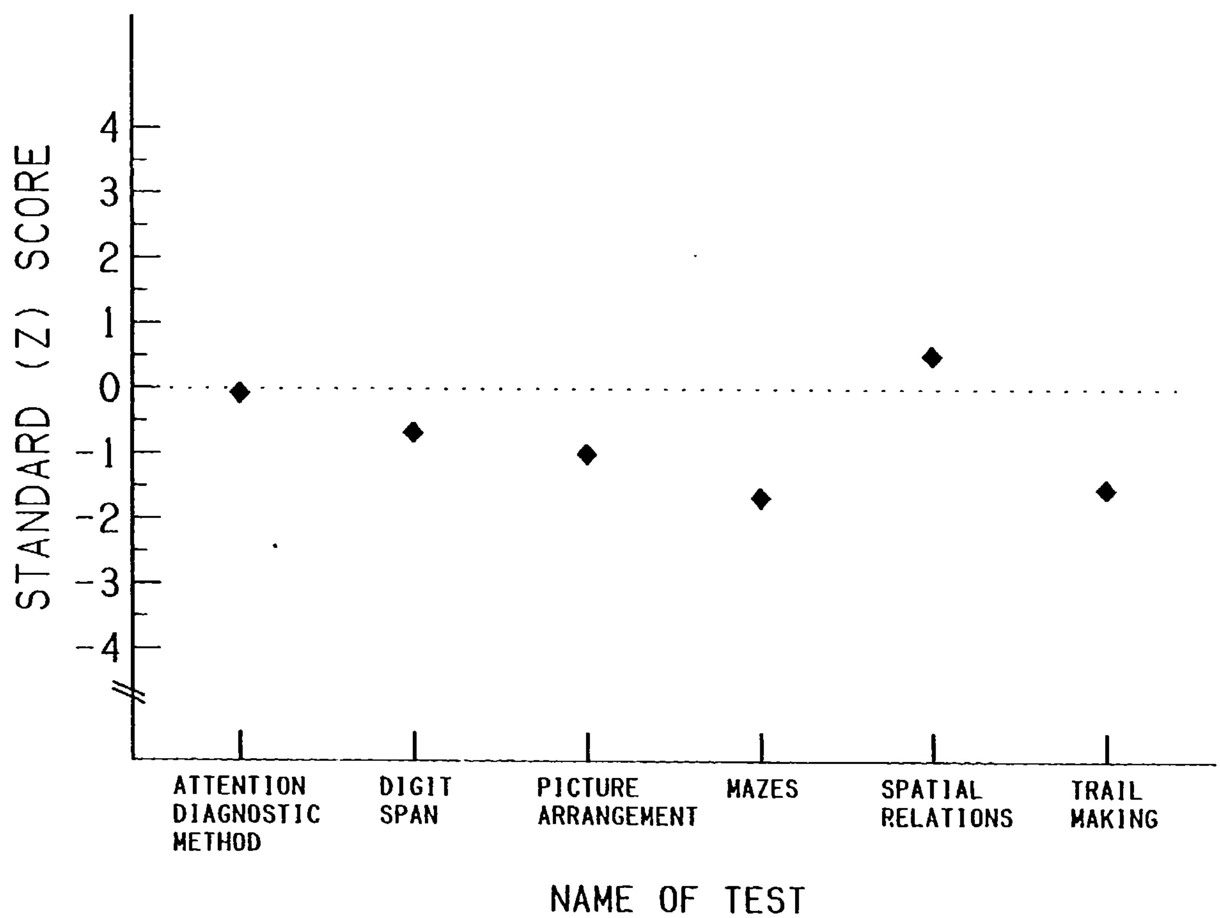

Figure 14. Neuropsychological test performance for U.T.

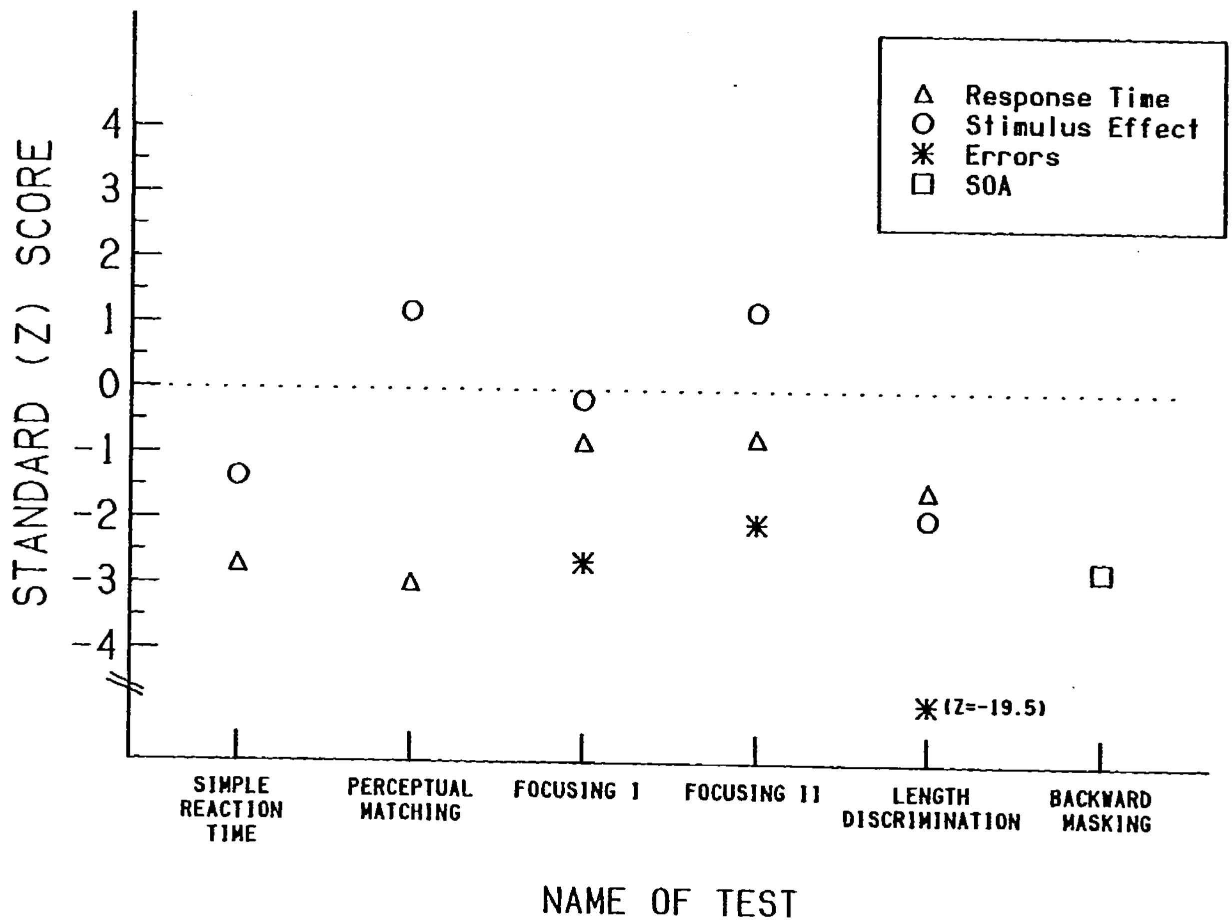

Figure 15. Information processing test performance for U.T.

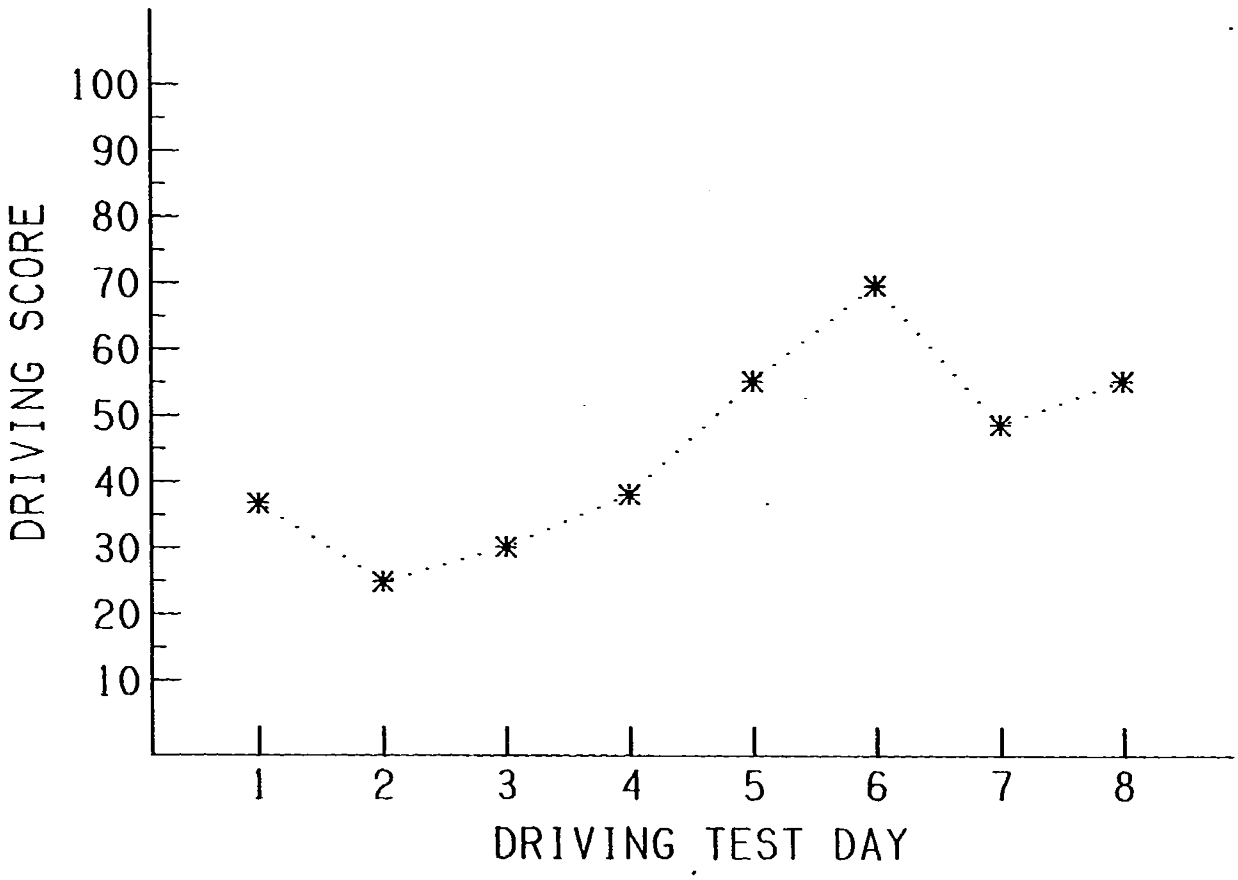

Figure 16. Road Test performance for U.T.

Case C.X.

C.X. was a 59-year-old female who had had a thrombo-embolic stroke eight years prior to the evaluation. The stroke affected circulation in the left middle cerebral artery distribution. She was totally aphasic during the days immediately following the stroke but had since regained near normal language ability. Although she showed residual right hemiparesis and wrote with her left hand (She was right handed prior to the stroke.), she was able to walk unassisted. No special controls were required for her to operate the driver-evaluation vehicle. Visual acuity, binocular depth perception, color perception, and lateral peripheral vision tested within normal limits. She had no hearing complaints.

Prior to the stroke, C.X. had been employed as a secretary.

Neuropsychological Tests. C.X.'s scores on the neuropsychological tests are shown on Figure 17. She scored within the normal range on the Attention Diagnostic Method and Digit Span tests, suggesting normal attention and short-term memory function. Her scores on Picture Arrangement and Spatial Relations were also within the normal range, suggesting normal comprehension and spatial abstraction ability. Her Trail Making Test score appears abnormal in Figure 17, but it is within the normal range for persons of her age. Her performance on the Mazes test was borderline abnormal. However, this test is like the Trail Making Test in that it requires tracing paths with a pencil: Although norms for older adults are not available for the Mazes test, it is reasonable to expect an age-related decline similar to that for Trail Making Test.

Information Processing Tasks. C.X.'s scores on the information processing tasks are presented in Figure 18. Her performance was average on the simple reaction time task, and her response time and SOA scores were low but within the normal range for her age on the length discrimination and backward masking tasks, respectively. In contrast, her response time scores were abnormally low (i.e., slow RTs) on the perceptual matching and focusing tasks. These findings suggest that she required an abnormal amount of time to process the more complex patterns used in those tasks. Part of her slowness may be accounted for by her age, but the age effect we have found on these tasks is relatively small.

C.X. also had abnormally high error rates for the focusing tasks. Since she made no errors on the perceptual matching task, it is likely that these errors indicate a visual memory problem. Finally, her stimulus effect scores were low (indicating high sensitivity to the stimulus parameters) for Focusing II and the length discrimination task but normal for Focusing I and the perceptual matching task. Interpretation of these stimulus effect findings would require additional evaluation.

Road Test. On initial evaluation, C.X.'s driving performance was relatively poor (see Figure 19). She showed poor speed regulation and hard braking. These problems could have resulted from the use of her right foot for the foot controls despite impaired sensory perception and motor control for that limb. Head turning, eye movement, awareness of traffic information, judgement, and independence were all rated "fair."

On her second evaluation, four days after the first, C.X. received "good" ratings in all areas except judgement and independence. She received the maximum possible ratings for evaluations 3 and 5, but on the 4th evaluation her judgement was rated as only "fair." On the last day, she successfully completed a road test given by an MVD examiner.

Relationship between performance measures. If her age is taken into account, C.X.'s performance was normal on all of the neuropsychological tests. Her response time scores on the information processing tasks suggested, however, that she had problems processing complex "letter like" visual patterns. Her high error rates on the focusing tasks suggest a memory problem for such patterns. These deficits certainly could increase the time required for sign interpretation and could interfere with retention when driving. Although they are a source of some concern, Bardach (1971) and Golper et al. (1980) found that such "verbal" impairments did not seriously affect driving ability. In accord with these findings, the driving instructor judged C.X. to be a competent driver.

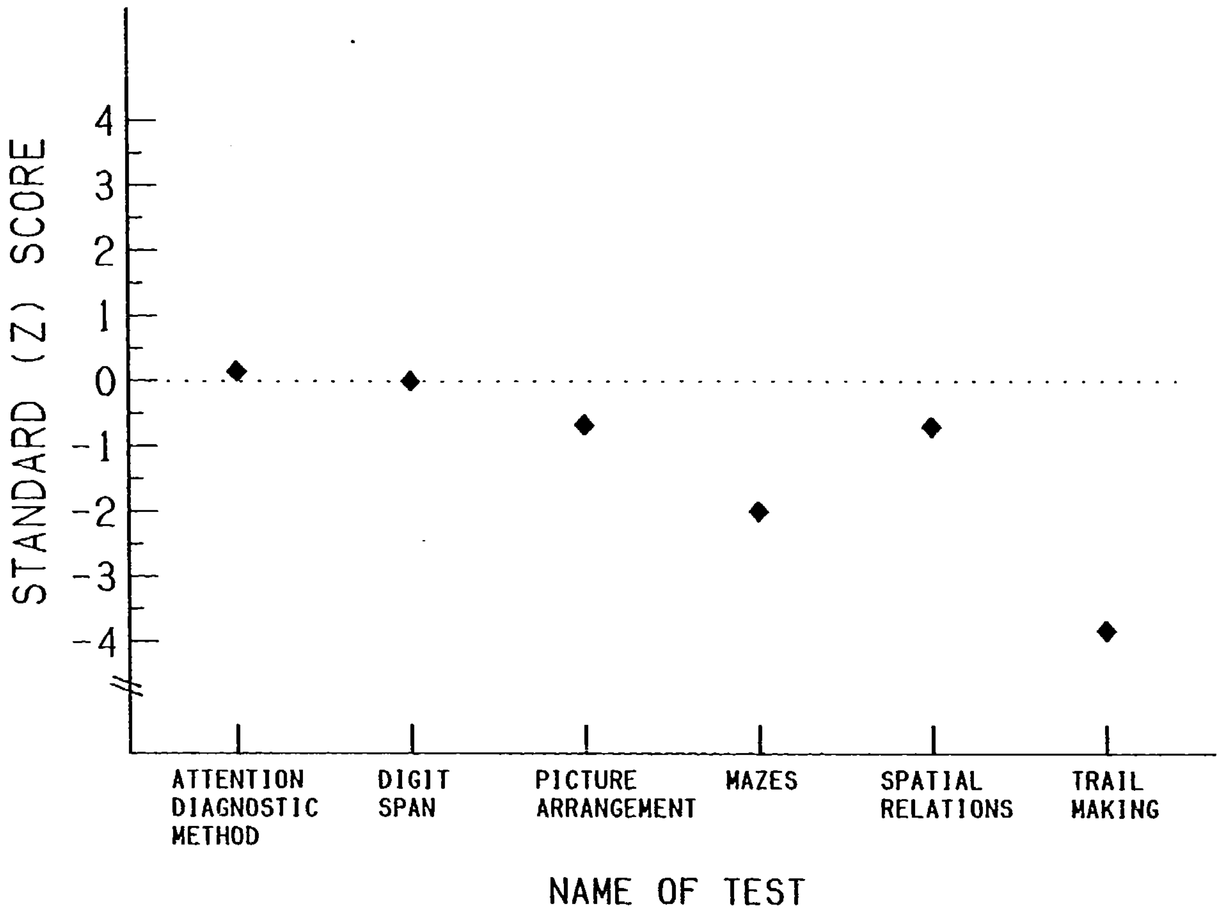

Figure 17. Neuropsychological test performance for C.X.

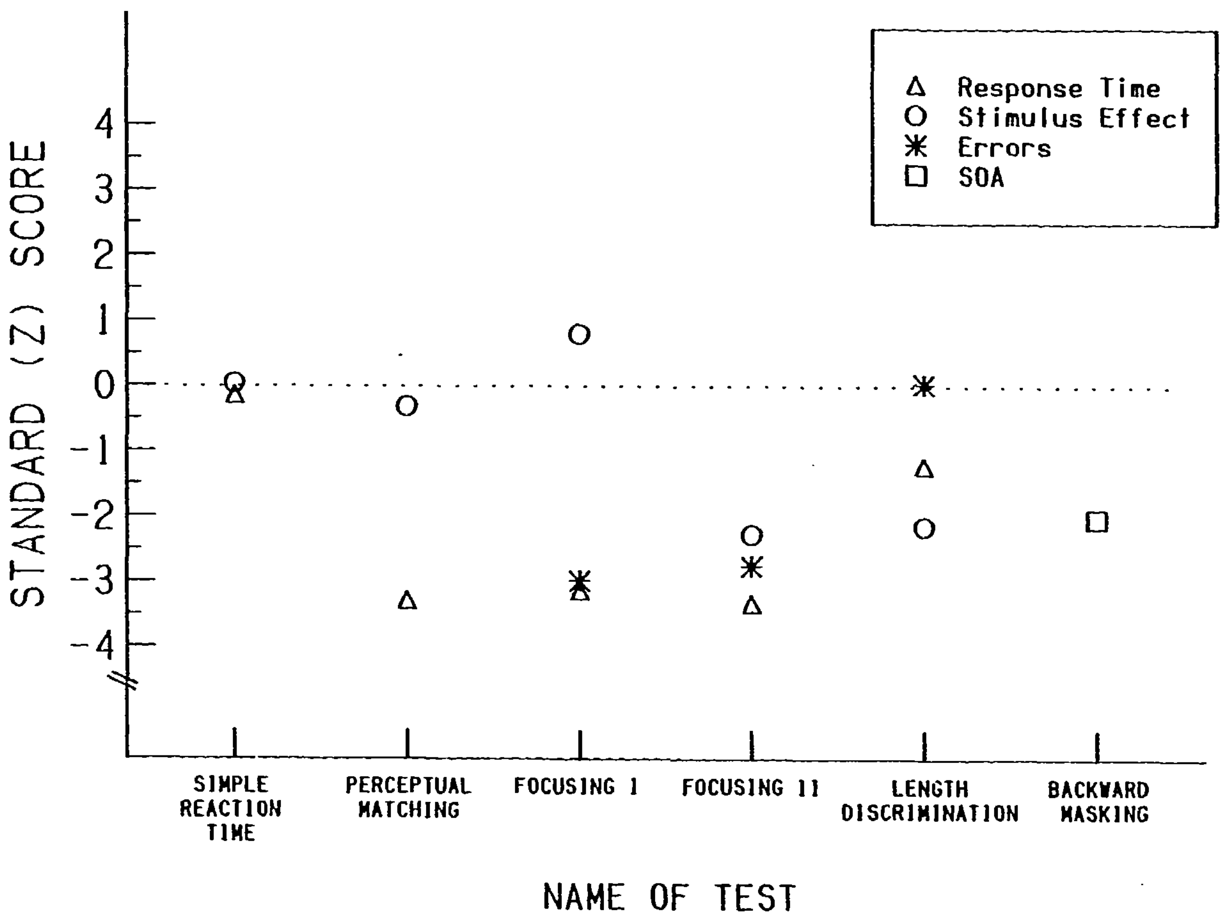

Figure 18. Information processing test performance for C.X.

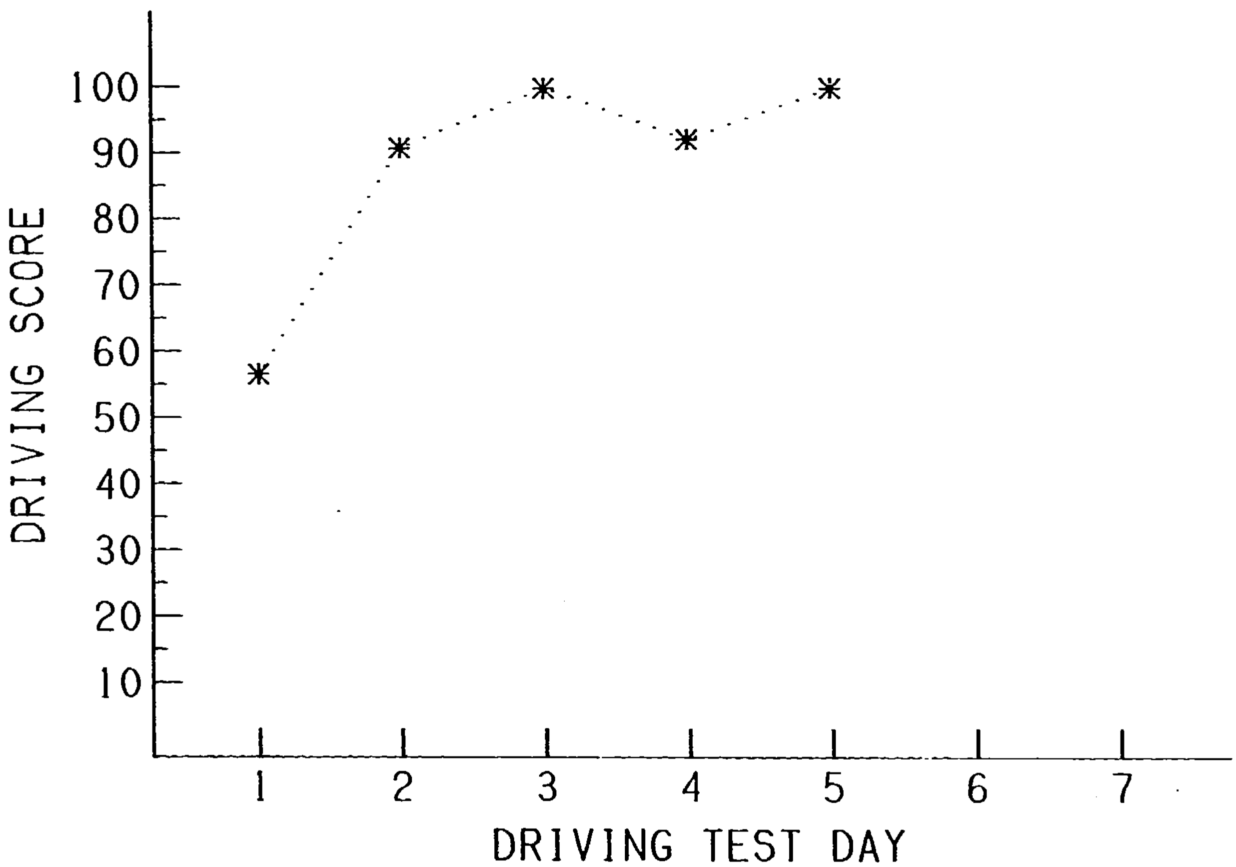

Figure 19. Road Test performance for C.X.

CONCLUSIONS AND RECOMMENDATIONS

Some brain-damaged people would pose a risk to themselves, other drivers, and pedestriansif they were to drive; others who suffer from quite restricted perceptual and cognitive deficiencies may be capable of safely operating a motor vehicle. Given the importance of driving in our society, it is incumbent upon us to assess the driving-relevant capabilities of brain-damaged individuals who wish to drive. Only then will we be able to adequately screen, advise, train, or develop compensatory devices to meet their needs and capabilities.

The need for research in this area is great and, as indicated by the cooperation of the Phoenix Baptist Hospital staff and patients, feasible within existing programs. Specifically, in this pilot research project, we were able to obtain measures of the perceptual and cognitive capabilities as well as evaluations of the driving performance of a small group of brain-damaged individuals. Additional testing of this nature, plus follow-up on the actual driving records of the individuals evaluated, would provide an invaluable data base for those tasked with developing policy and screening instruments for driver licensing.

Although improvements could be made in the information processing task battery used in this study (see Lindholm et al., 1986), this set of tasks did reveal deficits not detected by the neuropsychological tests that were administered. Indeed, the only patient whose driving competence was judged inadequate fell comfortably within the "normal" range on the neuropsychological tests but was shown to suffer from a severe impairment on the information processing tasks. While this finding was clearly fortuitous, it highlights the need for extensive testing of brain-damaged individuals who wish to drive.

It is impossible to estimate when scientific knowledge of normal human information processing capacities, of the effects of brain damage, and of the demands of the driving task will be sufficient to devise a totally adequate screening instrument for driver licensing. As knowledge increases, however, testing should become more relevant and more adequate. The existence of the Phoenix Baptist Hospital Adaptive Driving Center is an invaluable source of patients and on-the-road evaluation. It is recommended that the collaborative research effort begun with the Hospital be continued.

Greater involvement of the medical community would be extremely helpful in both the research and the assessment efforts. In this study, we were not able to obtain adequate information concerning the locus and extent of neurological damage suffered by the patients evaluated. Such information would increase the value of any behavioral data and could be used as a guide to individual testing.

Finally, it is important that any boards, committees, or panels appointed to set policy and/or review the capabilities of potential drivers include people who are experts in the area of human information processing -- namely, neuropsychologists and experimental psychologists with training in perception and cognition. Decisions as to the driving abilility of individuals who have suffered neurological damage should be made by individuals with extensive training in normal brain function and in the diversity of deficits that can result from brain damage.

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