UM-HSRI-80-3

PERCEPTUAL/COGNITIVE SKILLS AND DRIVING: EFFECTS OF BRAIN DAMAGE

Michael Sivak
Paul L. Olson
Donald G. Kewman
Hosik Won
Donald L. Henson

PREPARED FOR
THE UNIVERSITY OF MICHIGAN
REHABILITATION ENGINEERING CENTER

JANUARY 1980

THE UNIVERSITY OF MICHIGAN
HIGHWAY SAFETY RESEARCH INSTITUTE

Technical Report Documentation Page

1. Report No. UM-HSRI-80-3

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Perceptual/cognitive skills and driving:
Effects of brain damage.

5. Report Date January 1980

6. Performing Organization Code 016938

7. Author(s) Sivak, M., Olson, P. L., Kewman, D. G., Won, H., and Henson, D. L.

8. Performing Organization Report No. UM-HSRI-80-3

9. Performing Organization Name and Address
Highway Safety Research Institute (University of Michigan), Department of Physical Medicine and Rehabilitation (University of Michigan), and Huron High School (Ann Arbor, Michigan)

10. Work Unit No.

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
Office of Human Development
Rehabilitation Services Administration
Department of Health, Education and Welfare
Washington, D.C.

13. Type of Report and Period Covered

14. Sponsoring Agency Code

15. Supplementary Notes
This research was conducted for the University of Michigan Rehabilitation Engineering Center

16. Abstract

This study investigated the relation of perceptual/cognitive skills and driving. The subjects included 23 persons with brain damage, 8 persons with spinal-cord damage, and 10 able-bodied controls. Each subject was evaluated using a battery of perceptual and cognitive tests, a set of driving tasks in a parking lot, and actual in-traffic driving.

The main findings are as follows:

(1) Driving performance was significantly correlated with perceptual and cognitive skills. The highest correlations were obtained for Picture Completion Test (r = .71), Picture Arrangement Test (r = .58), and Motor Free Visual Perception Test (r = .57).

(2) The persons with brain damage performed significantly worse than the control subjects or people with spinal-cord damage on a range of perceptual and cognitive tests.

(3) The persons with brain damage exhibited impaired driving performance in relation to the control subjects or people with spinal-cord damage.

(4) The correlation between a subjective evaluation of driving potential by a driver trainer and an evaluation of selected driving actions proved to be rather high (r = .81).

(5) The obtained high correlations between several perceptual/cognitive tests and driving suggest that these tests (if properly validated) could be used in a screening battery to detect potentially serious driving-related problems.

(6) Statistical procedures indicate that the data are consistent with the following hypothesis: Brain damage affects perceptual and cognitive skills (including those evaluated by Symbol Digit Modalities Test, Picture Completion, and Picture Arrangement), which in turn affect driving performance.

17. Key Words
Driving, In-traffic driving, Brain damage, Spinal-cord damage, Perceptual skills, Perception, Cognitive skills, Cognition, Handicapped driver

18. Distribution Statement Unlimited

19. Security Classif. (of this report) Unclassified

20. Security Classif. (of this page) Unclassified

21. No. of Pages 54

22. Price

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

Appreciation is extended to:

Anne Neal, for administering and scoring the perceptual and cognitive tests,

Anne Hull, for advice on various aspects of the project,

Velsicol Chemical Corporation and especially Velsicol's Manager of Building Services, Mr. L. E. Pauling, for the use of the parking lot,

Lloyd Bridges Chevrolet, for the use of the test car,

Flora Simon, for efficient secretarial assistance, and

the 41 subjects without whom this study would not have been possible.

1.0 INTRODUCTION

Physical limitations are generally not the only consequence of brain damage. Frequently, other functions are impaired as well, including several psychological functions believed to be important to driving. These include perceptual skills (perceiving and reacting appropriately to one's environment and objects in it) and cognitive skills (reasoning, judgment, and other mental capabilities). For example, Bardach (1971) notes several frequent perceptual and cognitive deficits in hemiplegia, such as limitations of the visual field, confusion between left and right directions, inability to shift attention, inadequate scanning of the environment, and distractibility. Furthermore, there is also some experimental evidence (Sullivan et al., 1973) that perceptual and cognitive skills are related to driving potential in persons with brain damage. If,

(1) persons with brain damage suffer impairment in their perceptual and/or cognitive skills, and

(2) perceptual and cognitive skills are critical to daily activities such as driving,

then taking care of the physical limitations is going only part-way towards returning individuals with brain damage to normal life. Full rehabilitation would involve restoring their psychological functions to the pre-injury level as well.

The present study was designed to provide information regarding the following issues:

- Is driving performance correlated with perceptual and cognitive skills?
- Does brain damage result in impaired perceptual and/or cognitive skills?
- Does brain damage result in impaired driving potential?
- What is the relation between subjective evaluation of driving by a driver educator and an evaluation of selected driving actions?

Given positive answers to all four preceding questions, two additional considerations are of interest:

- Tests of the relevant perceptual and/or cognitive skills can then be incorporated into a screening procedure to evaluate driving potential of persons with brain damage. If valid, such a screening procedure would be less expensive, less time-consuming, and less dangerous (for both the prospective driver and driver educator) than the current practice of taking a drive in actual traffic.
- Can the driving problems experienced by some persons with brain damage be explained, at least in part, by their impaired perceptual and/or cognitive skills?

2.0 BACKGROUND

2.1 Driving Record of Persons with Brain Damage and with Physical Limitations

Research on the accident involvement of drivers with brain damage is virtually nonexistent. One of the few studies where such drivers were considered was by Crancer and McMurray (1968). In this investigation a group of drivers with medical licensing restrictions were divided into the following categories: diabetes, epilepsy, heart disease, vision deterioration, fainting, as well as a category "other conditions," which included psychological and neurological conditions, stroke, hypertension, alcoholism, drug addiction, etc. The group of interest here--other conditions--had a statistically higher accident rate than the non-restricted (general) population. However, since this group was a mixture of people with brain damage as well as people with no brain damage, it is unclear how relevant (for the present purposes) this finding is.

The data regarding drivers with physical limitations (with or without brain damage) are also rather limited. Most of the studies suggest that persons with physical handicaps, as a group, do not have a higher accident rate than the general population (e.g., Domey & Duckworth, 1963; Dreyer, 1973; Klingberg, 1979; Ysander, 1966). However, several studies that included a more detailed classification of drivers with various physical handicaps report that certain categories have worse accident records than the general population (e.g., drivers with loss of function in the right arm or leg [Ysander, 1966], and drivers requiring full hand controls [Negri & Ibisen, 1979]).

In summary, the relevant accident studies are rather sparse and do not provide separate information regarding drivers having physical handicaps with and without brain damage, which is critical in assessing the impact of brain damage per se on the accident involvement.

2.2 The Functional Asymmetry of the Human Brain[1]

The functional differences between the two hemispheres of the human brain have been known for over a century. Dax (1836) observed that language disturbances were associated with damage to the left hemisphere (cited in Critchley, 1962). Ever since the original observation of Dax, evidence has been accumulating that the hemispheres differ in performance of a variety of tasks. On the basis of this evidence several investigators postulate a basic dichotomy in the type of information processing by the two hemispheres (see Table 2.1).

Table 2.1. Postulated Hemispheric Differences in Information Processing.

	HEMISPHERE	
Authors	Left	Right
Zangwill (1961)	symbolic	visual-spatial
Levy-Agresti & Sperry (1968)	analytic	gestalt
DeRenzi, Scotti, & Spinnler (1969)	associational	apperceptive
Bogen (1969)	propositional	appositional
Cohen (1979)	verbal	visuospatial

One of the best-documented dichotomies is the dominance of the left hemisphere for verbal and language-related skills, and the dominance of the right hemisphere for nonverbal, perceptual skills. The research evidence for this dichotomy comes from three types of populations: persons with brain damage primarily to one hemisphere, persons with split brain, and the general population.

2.2.1 Persons with Brain Damage. Damage to the left hemisphere is more likely to lead to impairments in speech and in

---

[1] The material in this section has been abstracted primarily from Allard, 1972; Mountcastle, 1962; Milner, 1975; Nebes, 1974; and Polich, 1978. The interested reader is directed for a more detailed discussion to these works as well as to the following reviews: Dimond, 1972; Dimond & Beaumont, 1974; Gazzaniga, 1970; Blakemore et al., 1972; Kinsbourne, 1978; Kinsbourne & Smith, 1974.

retention of verbal material (e.g., Blakemore & Falconer, 1967; Corsi, 1972; Kim, 1976; Landsdell, 1968; Meyer & Yates, 1955; Milner, 1967, 1971; Faglioni, Spinnler, & Vignolo, 1970; Faglioni, Scotti, & Spinnler, 1969). Damage to the right hemisphere is more likely to lead to problems in perception and proprioception (e.g., Carmon & Bechfold, 1969; Cohen, 1959; Diller & Weinberg, 1965; DeRenzi, Faglioni & Spinnler, 1968; Ettlinger, 1960; Gainotti & Tiacci, 1971; Kimura, 1963; Landsdell, 1968; Milner, 1967, 1971; Zangwill, 1960).

2.2.2 Persons with Split Brain. In an effort to control epileptic seisures, a small number of patients have undergone a surgical section of the corpus calosum and the anterior commisure, which eliminates direct cross-communication between the two hemispheres but leaves the hemispheres relatively intact and functioning independently. The left hemisphere of such split-brain patients was found to be superior in tasks involving speech and writing (e.g., Gazzaniga, 1970; Gazzaniga & Sperry, 1967; Levy & Trevarten, 1976; Sperry, 1975). Analogously, the right hemisphere of the split-brain patients was found to be superior in perceptual/spatial tasks (e.g., Arrigoni & DeRenzi, 1964; Bogen, 1969; Bogen & Gazzaniga, 1965; Gazzaniga, 1965; Hécaen, 1962; Nebes, 1973).

2.2.3 General Population. Tachistoscopic presentations of visual material and dichotic presentations of auditory material can be used to present stimuli so that they are projected first to one of the two hemispheres of able-bodied subjects. The studies using these techniques indicate that the left hemisphere is more efficient on (visual and auditory) tasks containing verbal components (e.g., Broadbent & Gregory, 1964; Bryden, 1965, 1966, 1967, 1969; Geffen et al., 1971, 1972; Hines et al., 1973; Hannay & Malone, 1976; Iseroff et al., 1974; Kimura, 1961, 1966; McKeever & Gill, 1972a, 1972b; Moscowitch, Scullion, & Christie, 1976; Springer, 1971; Worral & Coles, 1976). On the other hand, the right hemisphere is more efficient on (visual and auditory) nonverbal perceptual tasks (e.g., Broadbent, 1971; Chaney & Webster, 1965; Curry, 1967; Dee & Fentenot, 1973; Geffen et al., 1971, 1972; Hilliard, 1973; Kimura, 1964; Murphy & Venables, 1970; Rizzolatti et al., 1971; Young & Ellis, 1976).

2.2.4 Conclusions. On the basis of the apparent specialization of the hemispheres, it would be expected that most persons with damage to their left hemisphere will show impairment on tasks involving verbal/cognitive (language-based) components, while those with damage to their right hemisphere will show impairment on tasks depending on visuo-spatial (language-free) capabilities. These expectations apply to laboratory tasks, where the degree of the relevant involvement of language can be manipulated. To the extent that driving involves language-free but also language-based activities (e.g., obeying speed signs, making turns on request, etc.), the predictions here are not straightforward.

3.0 METHOD

3.1 Overall Design of the Study

Of the 41 people who were tested, 24 had brain damage, 8 had spinal-cord damage, and 10 were able-bodied controls. Each person's performance was evaluated using three sets of tests:

(1) A set of 12 tests of perceptual and cognitive skills.

(2) A set of five driving tasks performed in a parking lot (closed-course driving measures).

(3) Actual, in-traffic driving.

To control for experimenter bias, the experimenters involved in the driving evaluation did not know the results of the perceptual and cognitive tests, which were administered by a different examiner.

3.2 Subjects

Three groups of subjects were included in the study. The first (experimental) group was composed of persons with a minimum one-year history of brain damage, the second group of orthopedically handicapped persons with spinal-cord damage, and the third group of individuals with no significant physical disabilities or history of brain damage. The group of persons with spinal-cord damage was included to control for some of the effects of physical disabilities common to persons with spinal-cord damage and persons with brain damage, such as decreased mobility and strength as well as the emotional concomitants of long-term physical disabilities.

The subjects for the first two groups were recruited from various health-service agencies in the local area. This included a speech and communication disorders clinic, a university hospital department of physical medicine and rehabilitation, local vocational-rehabilitation-service agencies, a center for independent living, a community hospital physical medicine and rehabilitation clinic, and a stroke club. The able-bodied subjects were recruited from a pool of student volunteers. A description of each group by age, sex, and nature of the disability is included in Table 3.1. (Among the persons with brain damage there were 13 who had suffered a stroke, 7 with traumatic head injury, and 3 with cerebral palsy.)

3.3 Procedure

During the first contact with subjects, they were given instructions regarding the purpose of the study, experimental procedures, amount of time required, possible risks. The types of activities the subjects would be doing was described. Subjects were then asked if they would like to participate in the study. They read or had read to them an informed consent form (see Appendix A). An appointment was then scheduled for perceptual/cognitive evaluation. This testing was conducted individually in a small, quiet office by the same examiner for all subjects. During testing, the subjects were provided with auditory instructions read by the examiner, and were also given written instructions to read, if they chose. The written instructions were printed in a large type so they could easily be read. The examiner simultaneously presented the subjects with both the auditory and printed instructions. The test examiner had several years of experience administering neuropsychological tests to physically and cognitively impaired patients. The testing took approximately two hours to complete.

Following the perceptual/cognitive evaluation, each subject was scheduled first for the closed-course and then for the open-road driving evaluation, both conducted on the same day.

3.4 Perceptual and Cognitive Tests

There is a variety of tests on the market claiming to evaluate various perceptual or cognitive abilities (see e.g., Anastasi, 1968; Buros, 1972, 1974; Chun, Cobb, & French, 1975). The tests that were eventually used were selected primarily on the basis of the following three considerations:

(1) The tests are designed to measure a skill with a "face" validity to driving. (In general, studies attempting to correlate a variety of skills with accident records yield

Table 3.1. Description of each group of subjects by nature of the disability, age, and sex.

DESCRIPTION		GROUP					
		Left Hemi[2] Lesion	Right Hemi[2] Lesion	Diffuse Lesion	Spinal-Cord Damage	Able-Bodied	Total
Number of Subjects		10	6	7	8	10	41
Number of Subjects by Sex	M	8	4	5	4	6	27
	F	2	2	2	4	4	14
Age	Mean	49.6	51.3	28.9	27.5	24.2	35.8 M F 36.5 34.4
	S.D.	12.1	14.7	11.2	7.8	5.4	15.4 M F 15.7 15.2
	Range	24-69	24-64	18-47	20-45	19-38	18-69 M F 18-69 20-64

---

[2] Since brain damage frequently results in motor problems on the contralateral side from the side of the lesion, persons with damage to the left hemisphere are frequently referred to as having right hemiplegia, and persons with damage to the right hemisphere as having left hemiplegia.

disappointingly low correlations [e.g., Goldstein, 1964; Henderson & Burg, 1974]. Studies correlating skills with driving performance are rather sparse [e.g., Sullivan, 1973]. Thus, the decisions regarding the relevancy to driving was based mainly on suggestions by researchers in the field of highway safety [e.g., Schlesinger, 1972; Shinar, 1978] as well as clinical observations of researchers in the field of rehabilitation [e.g., Bardach, 1963, 1969, 1971, 1973; Gurgold & Harden, 1978].)

(2) The tests involve a minimum of motor components.

(3) Clinical experience indicates that people with brain damage are likely to be deficient in the skills tested.

The actual 12 tests used are discussed below.

Ayres Space Test (Ayres, 1962a). According to the manual, "the major perceptual dimensions involved [in the Ayres Space Test] are perceptual speed and space visualization. The task involves deciding, through visual methods only, which of two blocks will fit a formboard [Ayres, 1962a, p.1]." Ayres (1962b) has found that subjects with brain damage showed a deficit in performance on this test. A shorter version of the test (all odd items) was used. The original instructions were followed. Both the raw and the time-adjusted scores were recorded.

Motor Free Visual Perception Test (Colarusso & Hammill, 1972). This is a multiple-choice test, requiring from the subject only a pointing response. The test contains items in five categories of visual perception: spatial relationships, visual discrimination, figure-ground, visual closure, and visual memory. Some of these perceptual functions have been shown to be affected by brain damage (e.g., Bardach, 1969; Warrington & James, 1967). The standard procedure was used.

Picture Completion (based on a subtest of the Wechsler Adult Intelligence Scale [Wechsler, 1955]). This is a test of perceptual discrimination, requiring the identification of missing elements in sketched figures. Research indicates that persons with brain damage perform worse on this test than control populations (e.g., Russell, 1972; Zimmerman & Woo-Sam, 1973). A 13-item shorter version of the original test was used (items # 1-7, 10, 12, 15-18) with essentially unmodified instructions.

Rod-and-Frame. This portable version of the original Witkin Rod-and-Frame test (e.g., Witkin & Asch, 1948) was developed by Oltman (1968). The test evaluates the perception of verticality in the presence of a limited visual field, a skill known to be affected by brain damage (e.g., Birch et al., 1960, 1961; Bruel et al., 1956, 1957; De Cenzio et al., 1970; Hulicka & Beckstein, 1961). In this test the subject views a rod within a square frame. The frame and the rod are pivoted at the same point in space which coincides with the center of both the frame and the rod. The subject's task is to set the rod (in the presence of a tilted frame) to the upright position. Witkin et al. (1962) argue that "for successful performance of this task the subject must extract the rod from the tilted frame through reference to body position [p. 36]." The subjects unaffected by the frame are referred to as field-independent; those affected by the frame, as field dependent.

The present study utilized Series 3 of the three series in the original test of field dependence (Witkin et al., 1962). In this series the subject sits erect (in the other two series the subject's body is tilted as well). Two measures of performance were obtained:

(1) Based on unsigned deviations: mean absolute error in degrees from the true upright for the eight trials of the series. Since this is the original measure proposed by Witkin (e.g., Witkin et al., 1962) it will be referred to here as the measure of field dependence.

(2) Based on signed deviations: mean signed error in degrees from the true vertical. It will be referred to here as the measure

of perception of verticality. (The eight trials involve four with the frame tilted clockwise and four counterclockwise. Therefore, a large score on this measure in either direction would indicate assymmetry in the effects of the two frame-tilts, possibly due to the assymmetry of the brain damage.) The original instructions by the apparatus manufacturer (Darro Products Corporation) were used.

Southern California Figure-Ground Visual Perception Test (Ayres, 1966). This test "is designed to assist in determination of deficits in visual perception which require selection of a foreground figure from a visual background [Ayres, 1966, p. 1]." This skill has been found to be affected by brain damage (e.g., Dolphin & Cruickshank, 1951; Harrover, 1939; Wood, 1955).

In this test the subject is presented with a series of plates consisting of superimposed or embedded pictures of common objects. The task requires the subject to point to three pictures of objects (out of the set of six alternatives) that are contained in the plate.

The standard procedure was used.

Symbol Digit Modalities Test (Smith, 1973). The task in this test is to substitute a number for a randomized presentation of geometric figures. The substitution is performed according to a key which pairs nine different figures with numbers from one to nine. Since the language symbols (digits) are presumably processed primarily by the left hemisphere, and language-free symbols (figures) by the right hemisphere, the substitution of numbers for geometric figures tests "the efficiency of many different central mechanisms in the two hemisphere [Smith, 1973, p. 1]." Smith (1968, 1969, 1971, 1972) has shown that this test is sensitive to brain damage.

The standard procedure was used.

Picture Arrangement (a subtest of the Wechsler Adult Intelligence Scale [Wechsler, 1955]). This test requires arranging pictures in each of eight series in proper sequence so that each series will tell a story. According to Zimmerman and Woo-Sam (1973), Picture Arrangement measures factors such as "visual perception, synthesis into wholes through planning, and ability to see cause-effect relationships [p. 154]." Visual perception and planning were observed to be impaired in persons with brain damage (Bardach, 1971). No modification of the instructions from the Wechsler Adult Intelligence Scale was made.

Porteus Maze (Porteus, 1933). This is a nonverbal task of tracing a path through a printed maze. The Porteus Maze was developed to measure aspects of intelligence which involve foresight, planning, anticipation, and rehearsal (Lezak, 1976; Porteus, 1959). Research indicates that the Porteus Maze is sensitive to the effects of head injury (Riddle & Roberts, 1974). The original testing procedure was used; however, the scoring method was based on the procedures of the University of Minnesota Neuropsychological Laboratory (Meier & Thomas, 1976).

Abstract Reasoning Test. The abstract reasoning test is a part of the Differential Aptitude Tests (Bennett, Seashore, & Wesman, 1947). It is designed to measure how easily, clearly, and well one can understand ideas and their relation to one another when problems are presented in terms of size, shape, position, quantity, or other non-verbal, non-numerical forms. Compared to a verbal reasoning test, the abstract reasoning test does not require a high level of verbal ability such as reading comprehension or vocabulary and thus is suitable for those who are limited in their verbal ability because of either traumatic brain damage, stroke, or congenital cognitive impairment. A modified version of the abstract reasoning test was assembled by selecting only some of the items. This was done in order to decrease the overall length of the testing battery to make it more likely that an eventual clinical version of the test would be of suitable length for routine use. It was decided to select items that were representative of the original test in terms of difficulty level, patterns, shapes, and form of the problems. Fifteen items (# 1, 4, 6, 19, 21, 22, 23, 26, 27, 32, 34, 38, 39, 42, 47) were compiled for the short version of the test, but the same test instructions were used as in the original version.

Arithmetic (based on the Arithmetic subtest of the Wechsler Adult Intelligence Scale [Wechsler, 1955]). As Zimmerman and Woo-Sam (1973, p. 84) point out, this test "provides clues to memory and concentration, particularly when paired with Digit Span [another subset of the Wechsler Adult Intelligence Scale]." The arithmetic subtest can also be considered as a measure of concentration and freedom from distractibility.

Considerations were given to the potential difficulty aphasics might have with the verbal expressive component of this test. It was decided to provide subjects with a number board in order to allow them to communicate their answers by pointing to the correct number on the number board. The test instructions were modified to accommodate the option of pointing to the correct answer. Despite the concerns, the examiner later found that even aphasic patients in our sample did not show any difficulty in responding. As a result, it was decided to discard this option after a few severely aphasic subjects were tested and found not to need or use the number board.

Digit Span (a subtest of the Wechsler Adult Intelligence Scale [Wechsler, 1955]). Digit Span is also reported to be a good measure of attention and freedom from distractibility (Zimmerman & Woo-Sam, 1973). In the present study, both the forward and backward digit span was administered according to the original instructions (Wechsler, 1955), except that the number board (described in the Arithmetic test) was initially offered to subjects, but was not utilized by even the more severely impaired aphasic subjects.

Vocabulary. The vocabulary test adopted for use in the present study involves matching words to pictures and thus does not require a verbal response. Ten items were taken from various subtests of the Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 1972) and these were used to construct a new set of word-picture matching pairs.

Goodglass and Kaplan (1972) indicate that word-picture matching involves comprehension of the meaning of written words. The original instructions for the Boston test were used without modification.

Five of the above tests are primarily perceptual tests (Ayres Space Test, Motor Free Visual Perception Test, Picture Completion, Rod-and-Frame, and Southern California Figure - Ground Visual Perception Test), four are primarily cognitive tests (Abstract Reasoning, Arithmetic, Digit Span, and Vocabulary), and three involve large components of both perception and cognition (Picture Arrangement, Porteus Maze, and Symbol Digit Modalities Test). (This division is obviously not clear-cut, since all tests involve both perceptual and cognitive aspects.)

In addition to the evaluation of perceptual/cognitive skills, each subject was tested using a Titmus Vision Tester (primarily to determine visual acuity) and a choice-reaction-time task (to obtain a measure of perceptual-cognitive-motor coordination and speed). In the reaction time task, the subject was asked to press one of the two response keys depending on which of two numbers was flashed. The dependent variable measured the combined period of time it took the subject to make a decision about which key to press, to move the hand to the key, and to depress the key.

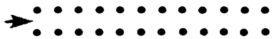
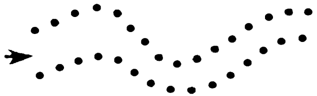
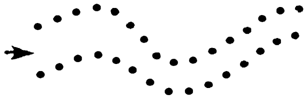
3.5 Closed-Course Driving

The closed-course driving evaluation was set up in a private parking lot. The tests utilized an area of approximately 225' x 150'.

Table 3.2 describes the tasks used, the scoring methods, and the probable skills contributing to the performance on each task.

The driving was done in a 1979 Chevrolet Caprice, equipped with a dual-brake system, hand controls for the accelerator and brake, and (if desired) a steering knob. A licensed driver educator, with extensive experience in working with persons with physical disabilities, rode in the test car and instructed the subject about the tasks to be performed. The driver educator demonstrated the execution of Tasks 1

Table 3.2. Driving tasks for the closed-course evaluation.

TASK	INSTRUCTIONS	DIAGRAM/NAME	DIMENSIONS AND OTHER SPECIFICATIONS[3]	WHAT IT IS SUPPOSE TO EVALUATE	SCORING
(1)	"Drive between the 2 lines without touching them."	 Straight tracking	Length: 180' Width: 6' 4" Number of cones: 40	Perceptual/motor coordination (tracking)	Number of knocked[4] and displaced cones
(2)	"Drive in a figure 8 pattern (around the two cones ahead of you) as fast as you can."	 Figure 8	Distance between the cones: 59'	Memory, steering reversals	Time
(3)	"Drive between the 2 lines without touching them."	 Curve tracking	Length: 155' Width: continuously narrowing from 9' to 7' Number of cones: 50	Perceptual/motor coordination (tracking)	Number of knocked and displaced cones
(4)	"When I tell you so, close your eyes, continue driving, and try to come to a stop next to the cone ahead of you."	 Blind stop	Distance from the cone at the time of closing the eyes: 100'	Memory, distance estimation	Distance away from the cone
(5)	Repeat of the task #3 with the addition of the following simultaneous loading tasks: "Make a sound whenever you hear a number." (The subject is listening to a sequence of words interspersed with numbers.)	 Curve tracking with a secondary task	Same as Task #3	Information processing capability, ability to perform two tasks simultaneously Perceptual/motor coordination (tracking)	Number of knocked and displaced cones Number of correct responses on the loading task

---

[3] The width of the test car at the point of contact with the cones in Tasks 1, 3, and 5 was 5' 2".

[4] "Knocked" is used as a shorthand for "knocked over."

and 3 individually to each subject. Furthermore, prior to Task 2 he asked each subject to draw a figure 8 around two points to assure that the instructions were well understood.

3.6 Open-Road Driving[5]

Each subject's in-traffic driving was evaluated on the same 10.4 mile course in the northeast section of Ann Arbor. The traffic on the route during the testing was light-to-moderate with light pedestrian traffic (with an exception of a pass through a shopping center). Approximately half of the route has a speed limit of 25 mph; additional sections have a limit of 30, 35, and 40 mph. Approximately two-thirds of the route is a two-lane road (with sections of one-way only); additional sections are four-lane wide (both divided and undivided) and five-lane wide (with a center turn lane). All driving was done during the daytime.

Each subject drove the same 1979 Chevrolet Caprice that was used for the closed-course driving. The car was equipped with dual-brake system, hand controls for accelerator and brakes, and (if desired) a steering knob. The above-mentioned driver educator (in the front seat) and a performance evaluator (in the rear seat) accompanied each subject. The performance evaluator was charged with rating the performance of each subject on 144 predetermined actions along the route. Figure 3.1 illustrates the route with all of the test actions and their locations on the route. (Due to the traffic conditions the actual number of the evaluated actions varied from subject to subject: the mean was 126.4 with a standard deviation of 8.5.)

The rating was done using a 2-point scale: Well executed and not well executed. The evaluated actions belonged to one of the following five categories:

Gap Acceptance. Did the driver, in merging into traffic, accept a gap of a safe size as opposed to accepting a gap too short or rejecting a gap long enough?

---

[5] Several aspects of the open-road evaluation were based on the research of Jones (1978).

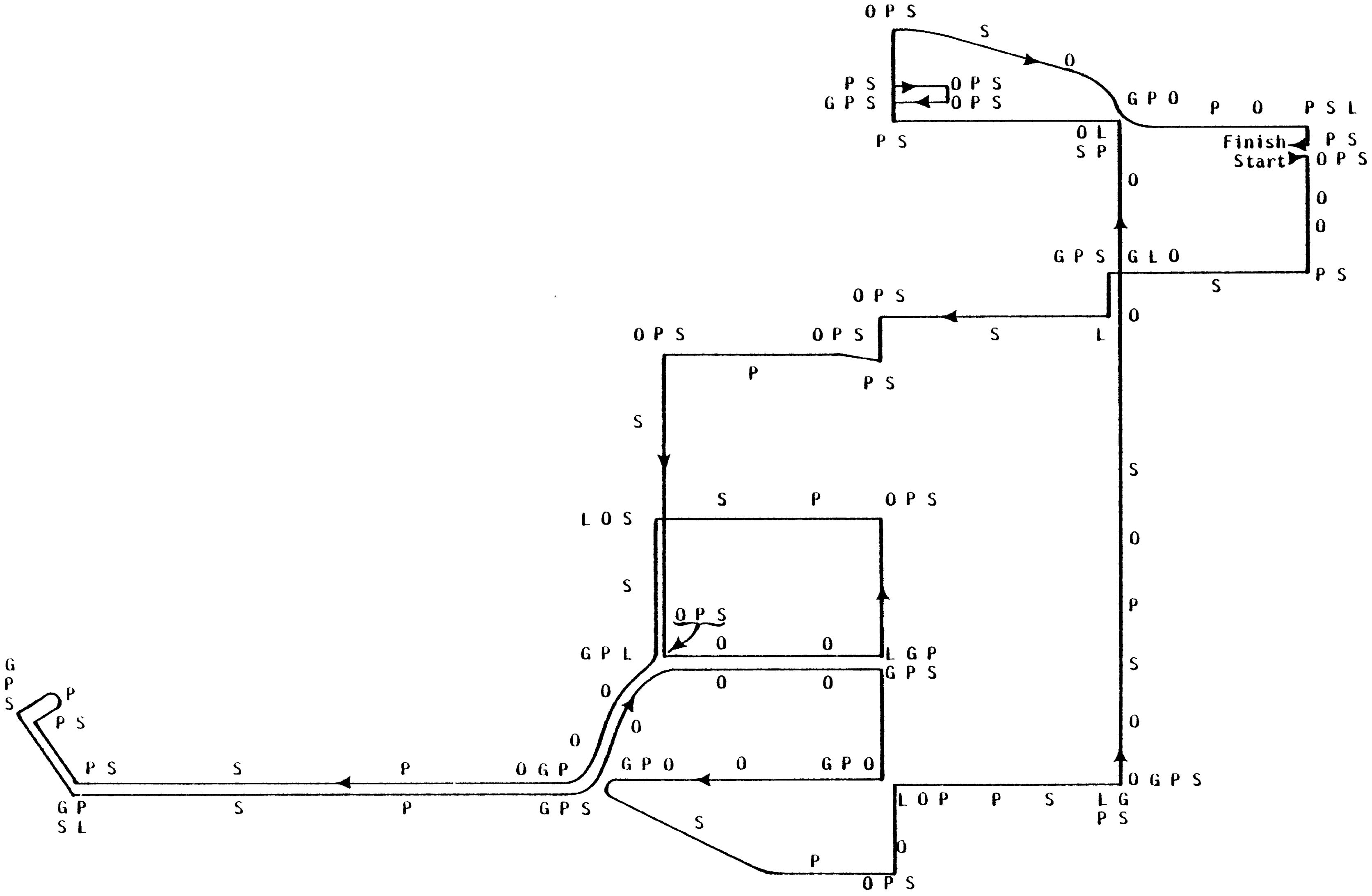


Figure 3.1 A schematic of the open-road driving course with the evaluated actions and their locations (G - Gap Acceptance, L - Limit Line, 0 - Observation, P - Path, S - Speed; for explanation see the text).

Limit Line. Did the driver position himself (herself) correctly at a stop sign, yield sign, or a traffic light?

Observation. Did the driver make the necessary observations (directly or via a mirror) at a stop or yield sign, prior to a requested change of lanes, and on turns? (Observations on turns and on straight portions were tabulated both separately and in aggregate.)

Path. Did the driver stay within his lane without unsafe deviations from the intended direction? (Paths on turns and straight portions were tabulated both separately and in aggregate.)

Speed. Did the driver stay within ± 5 mph from the speed limit? Did the driver maintain a smooth speed profile in turns and during acceleration? (Speeds on turns and straight portions were tabulated both separately and in aggregate.)

Two performance evaluators (both psychologists and one with prior experience in highway safety) alternated in rating the driving performance. They practiced prior to evaluating actual subjects by scoring the same pilot subjects and discussing the task with the driver educator. (The two evaluators exhibited a high inter-rater reliability: Scoring the same two subjects, they disagreed on only four out of a total of 224 test actions.)

At the conclusion of the closed-course and open-road driving, the driver educator evaluated each subject's driving potential, psychomotor skills, and perceptual/cognitive skills using rating scales in Appendix B. The driver educator made his ratings without the knowledge of the ratings by the performance evaluator.

4.0 RESULTS

4.1 Perceptual and Cognitive Skills

4.1.1 Effects of Brain Damage and Spinal-Cord Damage. The results of analyses of variance and *post hoc* t-tests for contrasts are presented in Table 4.1. These results indicate the following:

(1) The persons with brain damage performed significantly[6] worse than the controls on a range of perceptual and cognitive tests.

(2) The observed differences between persons with left and right hemiplegia are consistent with the hemispheric specialization discussed in Chapter 2 (the persons with left hemiplegia performing better on Arithmetic and Digit Span, but worse on the Motor Free Visual Perception Test).

(3) The persons with spinal-cord damage did not perform worse than the controls on any of the tests (with the exception of both forms of the Symbol Digit Modalities Tests). This finding suggests that the problems experienced by the people with brain damage were unlikely to be due to their physical limitations.

4.1.2 Factor Analysis. A factor analysis was performed on all laboratory tests (i.e., all perceptual and cognitive tests plus the visual acuity score and the reaction time). Table 4.2 shows the Varimax-rotated solutions obtained from the component analysis. As is apparent from Table 4.2, the following four factors emerged (with factor loadings in parentheses):

First factor - "general:perception/cognition" - being loaded primarily by

Porteus Maze (.87)
Motor Free Visual Perception Test (.79)
Reaction Time (-.72)
Abstract Reasoning (.70)

---

[6] $p < .05$ for all statistical tests throughout this report

Table 4.1 Perceptual and cognitive skills: Results of analyses of variance and t-tests for contrasts. The independent variable in the analyses of variance is the global diagnosis (persons with left hemiplegia [L], with right hemiplegia [R], with diffuse brain damage [D], with spinal-cord damage [S], and control subjects [C].) The entries under the t-tests for contrasts indicate the worse-performing group; no entry indicates no difference between the groups. (B - the combined group of people with either left hemiplegia, right hemiplegia, or diffuse brain damage.)

MEASURE	ANOVA	t-tests for contrasts					
		B vs. C	B vs. C+S	R vs. L	R vs. D	L vs. D	C vs. S
Motor Free Visual Perception Test	$p < .05$	B	B	L			
Rod-and-Frame, Unsigned Deviations	$p > .05$	B	B				
Rod-and-Frame, Signed Deviations	$p > .05$						
Symbol Digit Modalities Test, Oral Form	$p < .05$	B	B				S
Symbol Digit Modalities Test, Written Form	$p < .05$	B	B			D	S
Porteus Maze	$p < .05$		B				
Arithmetic	$p < .05$	B	B	R			
Digit Span	$p < .05$	B	B	R			
Ayres Space Test, Raw Score	$p > .05$						
Ayres Space Test, Adjusted Score	$p > .05$		B				
Abstract Reasoning	$p < .05$	B	B				
Southern California Figure Ground Test	$p < .05$	B	B				
Vocabulary	$p > .05$						
Picture Arrangement	$p < .05$	B	B				
Picture Completion	$p < .05$	B	B				
Visual Acuity	$p > .05$		B				
Reaction Time	$p < .05$	B	B				

Table 4.2. Perceptual and cognitive skills: Results of factor analysis.

TEST	FACTOR			
	(1)	(2)	(3)	(4)
Motor Free Visual Perception Test	.789	.075	.204	-.104
Rod-and-Frame, Unsigned Deviations	-.548	-.227	-.360	.122
Rod-and-Frame, Signed Deviations	-.012	-.043	-.014	-.916
Symbol Digit Modalities Test, Oral Form	.466	.306	.734	-.128
Symbol Digit Modalities Test, Written Form	.441	.204	.633	-.190
Porteus Maze	.872	.133	.125	.060
Arithmetic	.358	.149	.785	.041
Digit Span	.239	.157	.863	.019
Ayres Space Test, Raw Score	.545	-.291	.461	.173
Ayres Space Test, Adjusted Score	.668	-.036	.414	.228
Abstract Reasoning	.700	.065	.483	.109
Southern California Figure Ground Test	.501	.263	.556	-.188
Vocabulary	.161	-.146	.512	.118
Picture Arrangement	.632	.298	.362	.003
Picture Completion	.682	.236	.438	-.078
Visual Acuity	-.211	-.854	-.126	-.064
Reaction Time	-.716	.132	.433	.072

Picture Completion (.68)
Ayres Space Test, Adjusted Score (.67)
Picture Arrangement (.63)

Second factor - "visual acuity" - being loaded only by

Visual Acuity (-.85)

Third factor - "language, memory, distractibility" - being loaded primarily by

Digit Span (.86)
Arithmetic (.78)
Symbol Digit Modalities Test, Oral Form (.73)
Symbol Digit Modalities Test, Written Form (.63)

Fourth factor - "perception of verticality" - being loaded only by

Rod-and-Frame, Signed Deviations (-.92)

The first factor accounts for 30.7% of the common variance, while the second, third, and fourth factors account for additional 7.8, 24.7, and 6.3%, respectively.

Analyses of variance on the individual subjects' factor scores indicate that the global diagnosis (persons with left hemiplegia, right hemiplegia, diffuse brain damage, spinal-cord damage, and control subjects) had a significant effect on the factor scores of the first and third factor. Post hoc t-tests for contrasts revealed that for both of these factors, the factor scores for the combined group of people with brain damage differed significantly from those for the people with spinal-cord damage and control subjects. Similarly, for both of these factors, the factor scores for the persons with left hemiplegia differed from those for the persons with right hemiplegia, supporting the notion of hemispheric specialization.

4.2 Closed-Course Driving

4.2.1 Effects of Brain Damage and Spinal-Cord Damage. The results of analyses of variance and post hoc t-tests for contrasts are presented in Table 4.3. These results indicate the following:

(1) The persons with brain damage performed significantly worse than the controls on a range of measures.

Table 4.3. Close-course driving measures: Results of analyses of variance and t-tests for contrasts. The independent variable in the analyses of variance is the global diagnosis (persons with left hemiplegia [L], with right hemiplegia [R], with diffuse brain damage [D], with spinal-cord damage [S], and control subjects [C].) The entries under the t-tests for contrasts indicate the worse-performing group; no entry indicates no difference between the groups. (B - the combined group of people with either left hemiplegia, right hemiplegia, or diffuse brain damage.)

MEASURE	ANOVA	t-tests for contrasts					
		B vs. C	B vs. C+S	R vs. L	R vs. D	L vs. D	C vs. S
Number of knocked cones, Task 1	$p < .05$		B	R			
Number of displaced cones, Task 1	$p < .05$			R			
Total number of knocked and displaced cones, Task 1	$p < .05$	B	B	R	R		
Number of knocked and displaced cones on the left, Task 1	$p < .05$	B	B	L	D		
Number of knocked and displaced cones on the right, Task 1	$p < .05$		B	R	D		
Time, Task 2	$p > .05$						
Number of knocked cones, Task 3	$p > .05$	B	B				
Number of displaced cones, Task 3	$p < .05$	B	B		D	D	
Total number of knocked and displaced cones, Task 3	$p < .05$	B	B		D		
Number of knocked and displaced cones on the left, Task 3	$p < .05$	B	B	L	D		
Number of knocked and displaced cones on the right, Task 3	$p > .05$						
Distance from the target, Task 4	$p > .05$						
Number of knocked cones, Task 5	$p > .05$	B	B				
Number of displaced cones, Task 5	$p > .05$						
Total number of knocked and displaced cones, Task 5	$p < .05$	B	B				
Number of knocked and displaced cones on the left, Task 5	$p > .05$		B				
Number of knocked and displaced cones on the right, Task 5	$p < .05$			R		D	
Number of correct responses, Task 5	$p < .05$		B	R	R		

(2) The persons with right hemiplegia had problems with tracking on the right side, while those with left hemiplegia had problems on the left side, reflecting the contralateral effects of brain damage. Furthermore, the persons with right hemiplegia performed worse than those with left hemiplegia on the secondary, language-based task, which is consistent with hemispheric specialization discussed in Chapter 2.

(3) The subjects with spinal-cord damage did not perform differently from the controls on any of the measures. This finding suggests that the problems experienced by the people with brain damage were unlikely to be due to their physical limitations.

4.3 Open-Road Driving

4.3.1 Effects of Brain Damage and Spinal-Cord Damage. Out of the total of 41 people, two were judged by the driver educator (after the closed-course driving) as too dangerous to operate the vehicle on public roads. One of these two subjects was a person with left hemiplegia and one with a diffuse brain damage. The open-road driving of two additional people (both with a diffuse brain damage) was terminated for the same reason after a few minutes of actual driving. Thus, the analysis of the open-road driving is based on 37 subjects: ten with right hemiplegia, five with left hemiplegia, four with a diffuse brain injury, eight with spinal-cord damage, and ten controls. The best predictor of whether the subject completed the open-road course (N = 37) or did not (N = 4) were the following perceptual/cognitive tests:

Rod-and-Frame, Signed Deviations (r = -.57)
Symbol Digit Modalities Test, Written Form (r = -.40)
Symbol Digit Modalities Test, Oral Form (r = -.33)
Motor Free Visual Perception Test (r = -.32)

The results of analyses of variance and post hoc t-tests for contrasts are presented in Table 4.4. These results indicate the following:

(1) The persons with brain damage performed significantly worse than the control subjects on several measures.

Table 4.4. Open-road driving measures: Results of analyses of variance and t-tests for contrasts. The independent variable in the analyses of variance is the global diagnosis (persons with left hemiplegia [L], with right hemiplegia [R], with diffuse brain damage [D], with spinal-cord damage [S], and control subjects [C]. The entries under the t-tests for contrasts indicate the worse-performing group; no entry indicates no difference between the groups. (B - the combined group of people with either left hemiplegia, right hemiplegia, or diffuse brain damage.)

		t-tests for contrasts					
MEASURE	ANOVA	B vs. C	B vs. C+S	R vs. L	R vs. D	L vs. D	C vs. S
Observation on turns	$p < .05$		B	L		L	
Observation on straight portions	$p > .05$						
Observation on both turns and straight portions	$p > .05$						
Path on turns	$p < .05$	B	B				
Path on straight portions	$p > .05$		B				
Path on both turn and straight portions	$p < .05$	B	B				
Speed on turns	$p > .05$						
Speed on straight portions	$p > .05$						
Speed on both turns and straight portions	$p > .05$						
Gap acceptance	$p < .05$	B	B				
Limit-line behavior	$p > .05$						

(2) The persons with spinal-cord damage did not perform differently from the controls on any of the measures. This finding suggests that the problems experienced by the people with brain damage were unlikely to be due to their physical limitations.

4.3.2 Relation of Open-Road Driving to Perceptual/Cognitive Skills and Closed-Course Driving. As a global index of the open-road performance, a Composite Driving Index was computed, which was the mean of the percent correct scores of all evaluated driving actions:

Composite Driving Index = 1/8 times (% correct Observation on turns + % correct Observation on straight portions + % correct Speed on turns + % correct Speed on straight portions + % correct Path on turns + % correct Path on straight portions + % correct Gap acceptance + % correct Limit-line behavior)

The analysis of variance indicates that the persons with brain damage had a poorer Composite Driving Index than the combined group of control subjects and subjects with spinal-cord damage (84.5 vs. 94.4). The results of the correlational analysis indicate that the following measures were significantly correlated with the Composite Driving Index (the correlation coefficient is in parentheses):

Picture Completion	(.71)
Picture Arrangement	(.58)
Motor Free Visual Perception Test	(.57)
Porteus Maze	(.55)
Abstract Reasoning	(.54)
Symbol Digit Modalities Test, Oral Form	(.53)
Symbol Digit Modalities Test, Written Form	(.51)
Southern California Figure Ground Test	(.50)
Rod-and-Frame, Unsigned deviations	(-.44)
Digit Span	(.41)
Arithmetic	(.41)
Ayres Space Test, Adjusted Score	(.41)
Ayres Space Test, Raw Score	(.35)
Reaction Time	(-.52)

Total number of cones knocked and displaced, Task 3	(-.56)
Number of cones knocked, Task 3	(-.55)
Number of cones knocked and displaced on the left, Task 1	(-.44)
Number of cones knocked, Task 5	(-.44)
Number of cones knocked and displaced on the left, Task 3	(-.44)
Number of correct responses, Task 5	(.41)
Number of cones knocked and displaced on the left, Task 5	(-.33)
Number of cones displaced, Task 3	(-.33)

The preceding analysis implies that knowing the score on the Picture Completion test, one can account for 50% of the variance of the open-road driving performance. Analogously, the Picture Arrangement Test and the Motor Free Visual Perception Test can account for 34 and 32% of the variance of the open-road driving, respectively.

The best predictor of the open-road performance from the closed-course measures was the total number of cones knocked and displaced in Task 3 (curve tracking), accounting for 31% of the variance. Interestingly, among the best predictors of in-traffic driving were all three measures of the tracking errors on the driver's (left) side.

The above analyses were performed for all groups of subjects simultaneously. Analogous correlational analyses were also performed for the people with brain damage and a combined group of controls and people with spinal-cord damage. For the persons with brain damage, Picture Completion (r = .72) and Picture Arrangement (r = .46) were significantly correlated with the Composite Driving Index. For the combined group of control subjects and subjects with spinal-cord damage, the following measures were correlated with the Composite Driving Index:

Porteus Maze	(.77)
Rod-and-Frame, Unsigned deviations	(-.62)
Abstract Reasoning	(.55)
Ayres Space Test, Adjusted score	(.52)

Total number of cones displaced or knocked, Task 3	(-.72)
Number of cones knocked, Task 3	(-.68)
Number of cones knocked or displaced on the right, Task 3	(-.66)
Number of cones knocked, Task 5	(-.58)
Number of cones knocked and displaced on the right, Task 5	(-.57)
Number of cones knocked and displaced on the left, Task 1	(-.54)
Total number of cones knocked or displaced, Task 5	(-.51)
Number of cones displaced, Task 3	(-.48)

Correlational analysis of the individual factor scores (from the factor analysis of the laboratory measures, p. 22) and the Composite Driving Index indicates that the factor scores for the first factor ("general:perceptual/cognitive") were significantly related to the driving performance (r = .59). The factor scores for the other three factors were not significantly related to the driving performance.

4.3.3 Effects of Demographic Variables on Open-Road Driving. The following demographic measures were not significantly correlated with the Composite Driving Index:

Sex
Educational status (in or out of school)
Preferred hand
Age
Years of education
Total number of months of driving experience
Number of months of driving prior to the injury } Analyzed for the
Number of months of driving since the injury } persons with brain
Number of months from the injury } and spinal-cord damage

Additional analyses were performed by dividing subjects into three pairs of groups, respectively:

- No driving experience <u>at all</u> vs. some driving experience (all subjects)
- No driving experience <u>prior</u> to the injury vs. some driving experience <u>prior</u> to the injury (subjects with brain or spinal-cord damage)
- No driving experience <u>since</u> the injury vs. some driving experience <u>since</u> the injury (subjects with brain or spinal-cord damage)

Analysis of variance revealed that the Composite Driving Index did not differ for the people with no driving experience <u>at all</u> in comparison to those with some driving experience. A similar dichotomy on the driving experience <u>prior</u> to the injury suggested no effect on the Composite Driving Index. However, the people who had some driving experience <u>since</u> the injury performed better than those who had none. (This finding suggests that either (1) the people who drove worse did so because they had no post-injury driving experience, or more plausibly, (2) the people who had no post-injury driving experience did so because they were worse drivers due to their injury.)

4.4 Subjective Evaluation of Driving Performance

At the conclusion of the closed-course and open-road driving, the driver educator evaluated each subject by using the rating scales in Appendix B. Statistical analyses of his ratings indicate that the persons with brain damage were judged to have

(1) lower driving potentials,

(2) poorer psychomotor skills, and

(3) poorer perceptual and cognitive skills

than the controls. The correlation coefficients of these three subjective evaluations with the objective Composite Driving Index were .81, .77, and .74, respectively. These findings imply that the utilized measure of the driving performance evaluated, to a great extent, similar behaviors as the traditional subjective evaluations by an experienced driver educator.

4.5 Perceptual and Cognitive Skills as Mediators between Brain Damage and Problems in Driving

The analyses of variance of the Composite Driving Index indicate that the driving performance of persons with brain damage differed from that of the controls ($p = .025$) or that of the combined group of controls and people with spinal-cord damage ($p = .002$). To investigate the hypothesis that the driving problems experienced by the persons with brain damage stem from their perceptual and cognitive deficiencies, analyses of covariance were performed. In these analyses the dependent variable was the Composite Driving Index (CDI), the independent variable was the two subject populations (people with brain damage and a combined group of controls and people with spinal-cord damage) and the covariates were each of the perceptual/cognitive and closed-course measures which were significantly correlated with CDI (see p. 27). The results of these analyses are presented in Table 4.5. As is evident from these findings, adjusting the two group means of the CDI on one of several perceptual/cognitive measures resulted in no statistical difference between the persons with brain damage and the remaining subjects. The most effective such measures include both versions of the Symbol Digit Modalities Test, Picture Arrangement, and Picture Completion. These results are consistent with the hypothesis that brain damage affects perceptual/cognitive skills which, in turn, affect driving performance.

4.6 Predicting the Driving Performance: Variable-Selection Procedure

A variable-selection method (see, e.g., Draper & Smith, 1966) was applied separately to all perceptual and cognitive measures, closed-course driving measures, and the combined set of perceptual/cognitive and closed-course measures. The procedure selects the independent variables for a regression model using a stepwise regression. The dependent variable was the Composite Driving Index (CDI). The resulting models are as follows:[7]

(1) All perceptual/cognitive measures:

CDI = 55.21 + 3.33 x (Picture Completion score).
Percent of the variance accounted for (r^2) = .51

(2) All closed-course measures:

CDI = 74.16 - .99 x (Total number of cones knocked and displaced, Task 3) + 2.21 x (Number of correct responses, Task 5) - 2.70 x (Number of cones knocked and displaced on the left, Task 1)
Percent of the variance accounted for (r^2) = .51

(3) Combined set of the perceptual/cognitive and closed-course measures:

CDI = 59.80 + 3.04 x (Picture Completion score) - 1.13 x (Number of cones knocked and displaced on the left, Task 3)
Percent of the variance accounted for (r^2) = .59

---

[7] The results of these analyses should be evaluated with caution, because of the relatively large number of measures (in relation to the number of subjects) entering into the selection process.

Table 4.5. Analyses of covariance. The dependent variable is the Composite Driving Index (CDI). The test for equality of means is for the persons with brain damage vs. controls and persons with spinal-cord damage. (These results should be compared to p = .002 for the equality of unadjusted means, obtained from analysis of variance.)

COVARIATE	Equality of adjusted means (obtained p level)
Motor Free Visual Perception Test	.085
Rod-and-Frame, Unsigned Deviations	.015
Symbol Digit Modalities Test, Oral Form	.336
Symbol Digit Modalities Test, Written Form	.224
Porteus Maze	.031
Arithmetic	.038
Digit Span	.040
Ayres Space Test, Raw Score	.007
Ayres Space Test, Adjusted Score	.009
Abstract Reasoning	.057
Southern California Figure-Ground Test	.084
Picture Arrangement	.178
Picture Completion	.132
Reaction Time	.092
Number of knocked and displaced cones on the left, Task 1	.006
Number of knocked cones, Task 3	.017
Number of displaced cones, Task 3	.010
Total number of knocked and displaced cones, Task 3	.033
Number of knocked and displaced cones on the left, Task 3	.010
Number of knocked cones, Task 5	.035
Number of knocked and displaced cones on the left, Task 5	.008
Number of correct responses, Task 5	.022

5.0 SUMMARY, DISCUSSION, AND CONCLUSIONS

The discussion here is centered around the primary questions of interest, stated in Chapter 1 (pp. 1, 2).

(1) Is driving performance correlated with perceptual and cognitive skills?

The results of the correlational analysis (p. 27) indicate that performance on most of the perceptual and cognitive tests was significantly correlated with open-road driving. The highest correlations were obtained for the Picture Completion Test ($r = .71$), Picture Arrangement Test ($r = .58$), and Motor Free Visual Perception Test ($r = .57$).

(2) Does brain damage result in impaired perceptual and cognitive skills?

As is evident from Table 4.1, the answer is "yes." On most of the tests, the people with brain damage scored significantly worse than the controls. On the other hand, the performance of the people with spinal-cord damage, in general, did not differ from that of the control subjects. This finding implies that the problems encountered by the individuals with brain damage are likely not due to their physical limitations.

(3) Does brain damage result in impaired driving performance?

Results of analyses of variance (pp. 23-27) indicate that persons with brain damage performed significantly worse than the controls (or the combined group of the control subjects and persons with spinal-cord damage) on several measures of both the closed-course and open-road driving.

(4) What is the relation between subjective evaluation of driving by a driver educator and an evaluation of selected driving actions?

The correlational analysis (p. 30) indicates that the correlation between a global subjective evaluation of driving potential by a driver educator and an evaluation of selected driving actions is rather high (r = .81). This finding implies that the utilized measures of driving performance evaluated to a great extent similar behaviors as the traditional subjective evaluations.

(5) Can the tests that are correlated with driving be incorporated into a screening procedure to evaluate driving potential of persons in general and persons with brain damage in particular?

The results of this study suggest that there are several potential candidates for inclusion in a screening battery (e.g., Picture Completion, Picture Arrangement, Motor Free Visual Perception Test.) The scatter plots of the best predictor of the open-road driving (Picture Completion) vs. a measure of open-road driving (Composite Driving Index) are shown in Figures 5.1 nad 5.2 for all subjects and the persons with brain damage, respectively. The analogous scatter plots using regression models having two predictors are shown in Figures 5.3 and 5.4. (The predicted values for plots in Figures 5.3 and 5.4 were derived from the results of a stepwise regression analysis, p. 31.) While these results are encouraging, validations with larger samples of people with brain damage are necessary.

The obtained correlation coefficients between the best predictors (Picture Completion, Picture Arrangement, and Motor Free Visual Perception Test) and driving (.71 - .57) fall substantially short of 1.00. Therefore, it is unlikely that any of these tests will replace the actual driving test. However, their predictive power is high enough so that they might prove to be valuable tools in rapid detection of potentially serious driving-related problems.

(6) Can the problems in driving experienced by some people with brain damage be explained, at least in part, by their impaired perceptual/cognitive skills?

The results of the analyses of covariance (p. 32) indicate

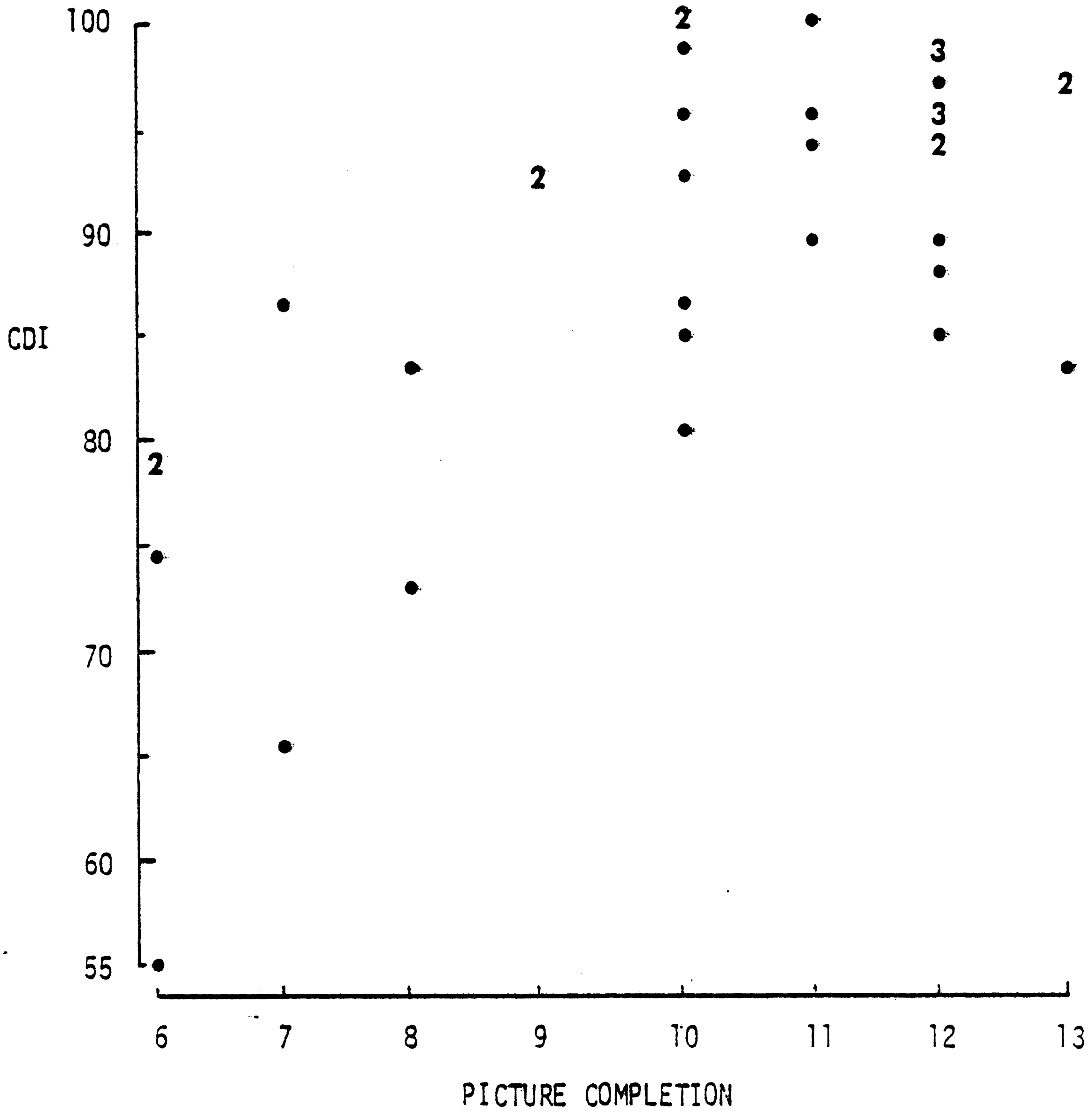


Figure 5.1 Scatter plot of the Composite Driving Index (CDI) vs. Picture Completion score. All subjects.

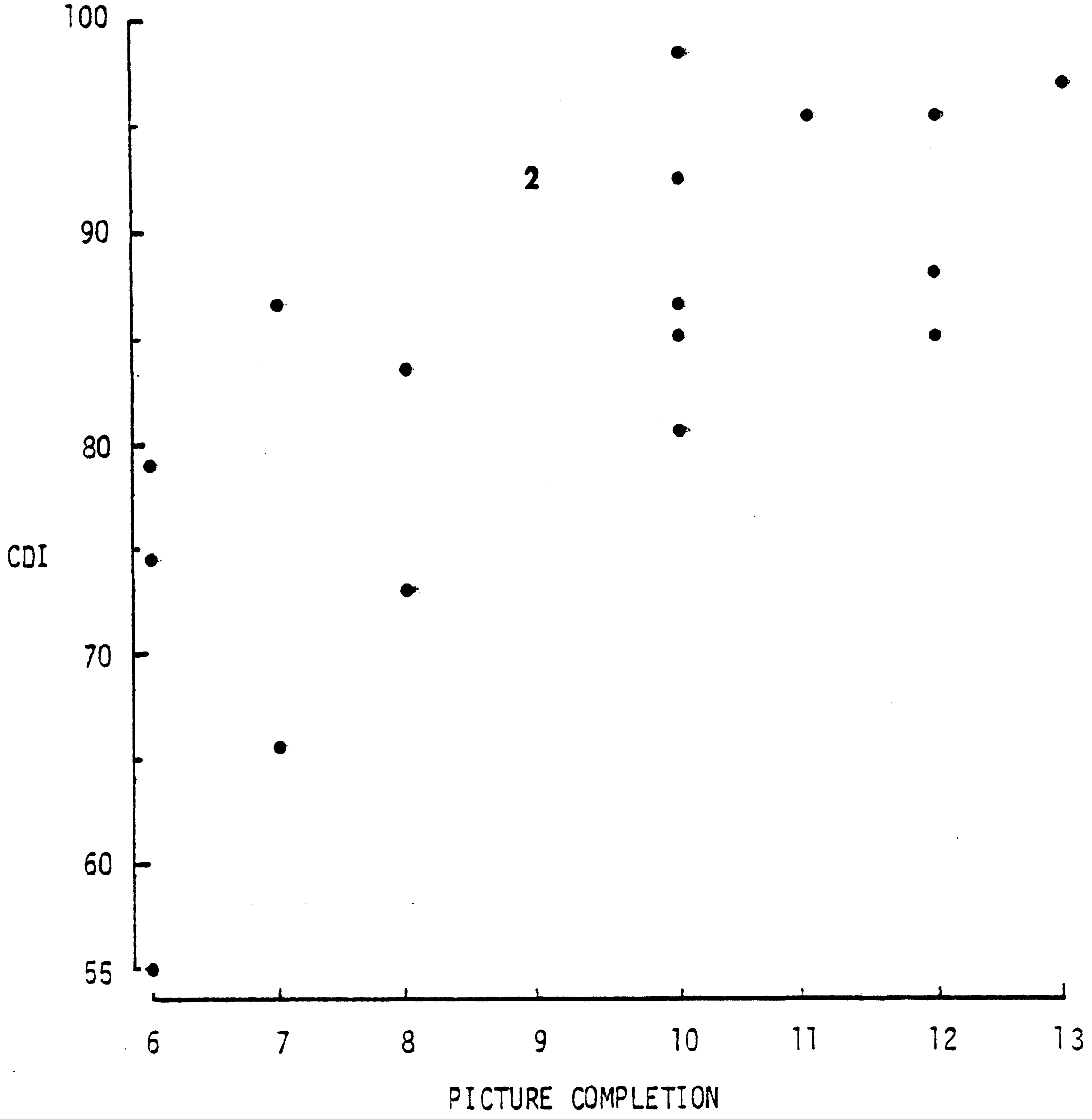


Figure 5.2 Scatter plot of the Composite Driving Index (CDI) vs. Picture Completion score. Persons with brain damage only.

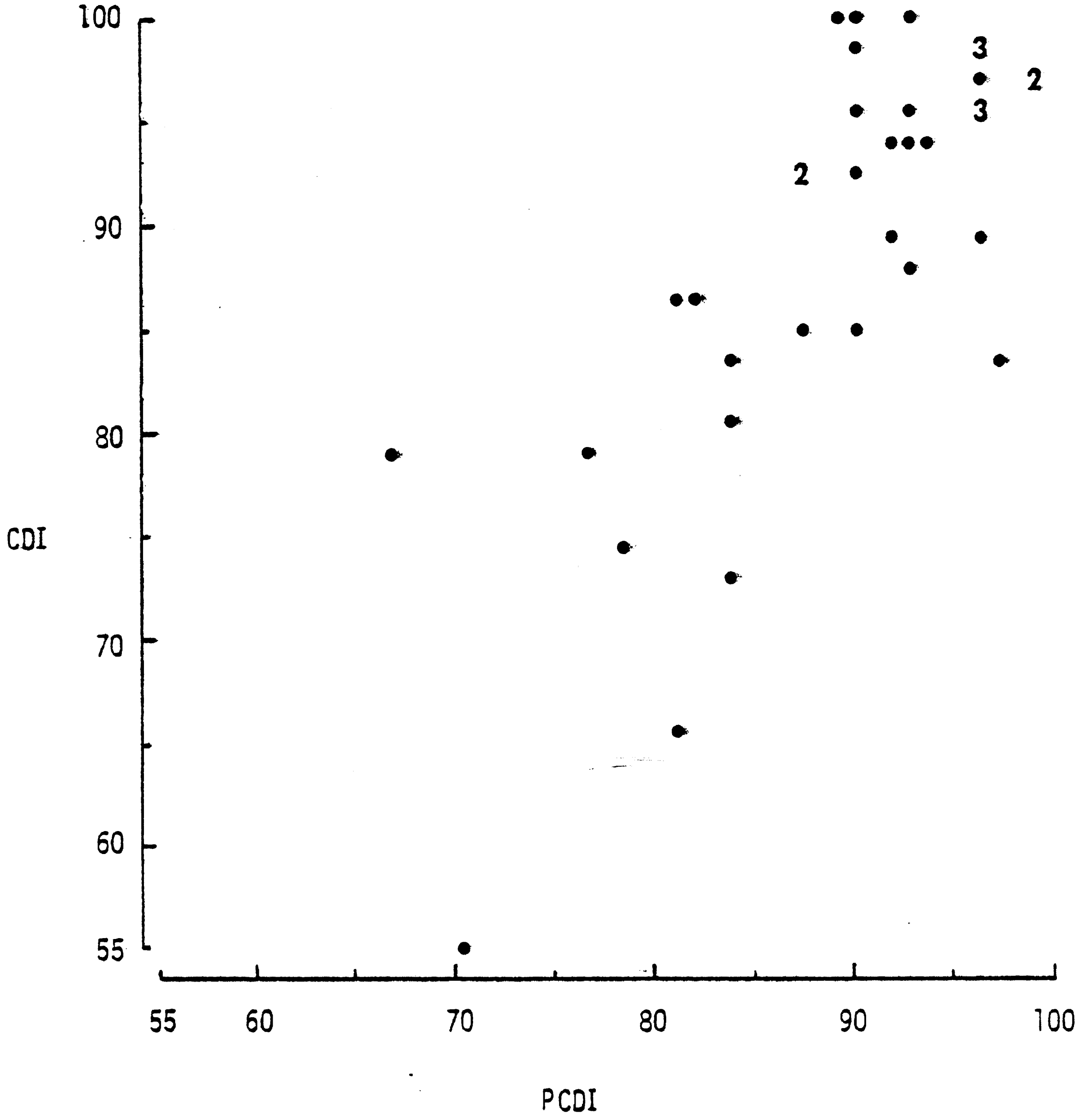


Figure 5.3 Scatter plot of the Composite Driving Index (CDI) vs. predictions (PCDI) from a regression model using two predictors (Picture Completion and Number of cones knocked and displaced on the left, Task 3). All subjects.

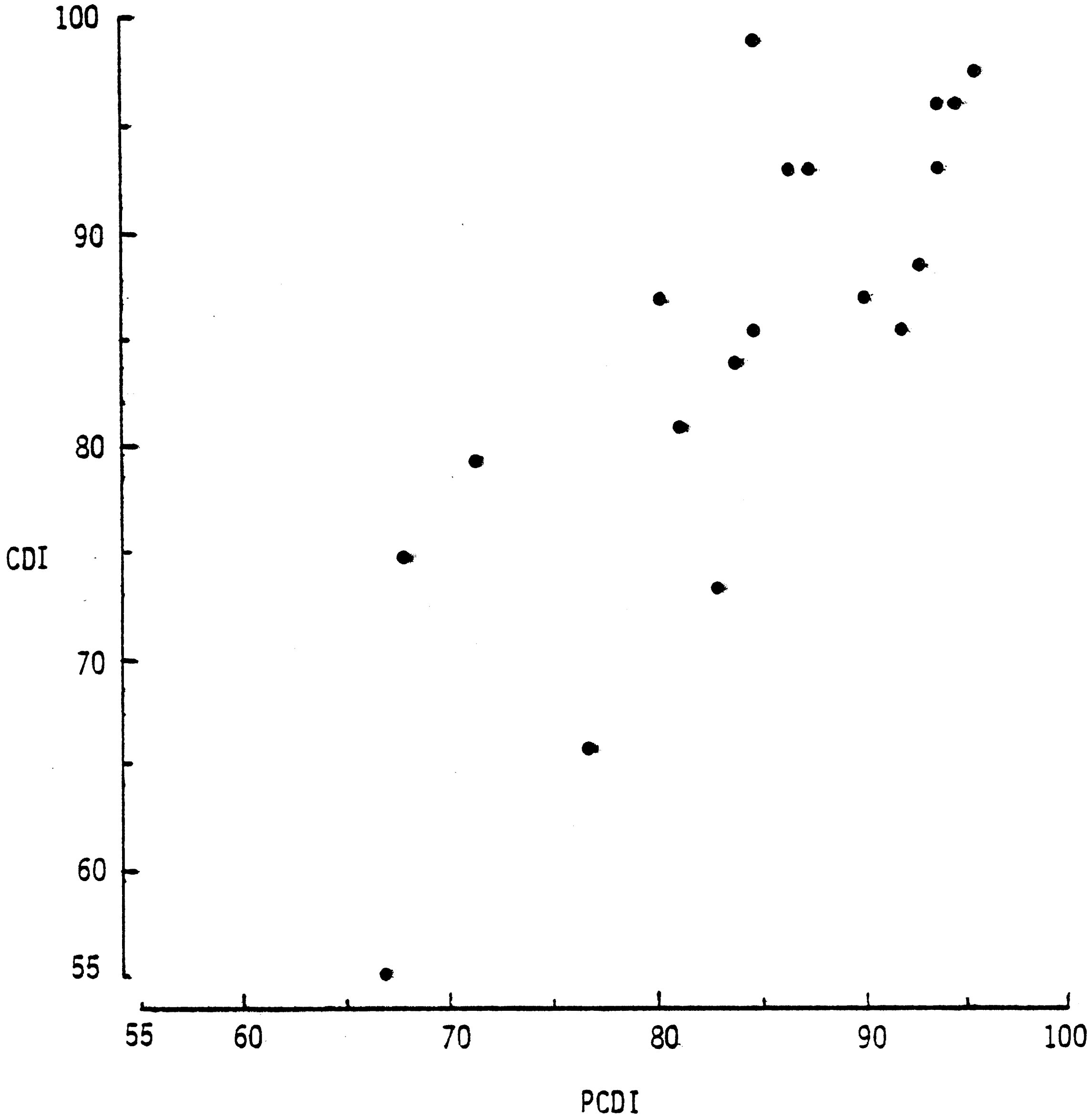


Figure 5.4 Scatter plot of the Composite Driving Index (CDI) vs. predictions (PCDI) from a regression model using two predictors (Picture Completion and Arithmetic). Persons with brain damage only.

that the present data are consistent with the hypothesis that several perceptual and cognitive skills are mediators between the effects of brain damage on driving performance. (This hypothesis states, in other words, that brain damage affects perceptual/cognitive skills which, in turn, affect driving performance.) The most likely candidates for such mediators are the skills evaluated by Symbol Digit Modalities Test, Picture Arrangement, and Picture Completion. Therefore, rehabilitation techniques which would improve the skills evaluated by these tests are likely to improve the driving potential of the persons with brain damage.

REFERENCES

Allard, F. Cerebral dominance. In M. Coltheart (Ed.), Readings in cognitive psychology. Toronto: Holt, Rinehard and Winston of Canada, 1972.

Anastasi, A. Psychological testing, 3rd Edition, New York: Macmillan, 1968.

Arrigoni, G., and E. DeRenzi. Constructional apraxia and hemispheric locus of lesion. Cortex, 1964, 1, 170-197.

Ayres, A. J. Ayres Space Test, Manual. Los Angeles, California, Western Psychological Services, 1962. (a)

Ayres, A. J. Perception of space of adult hemiplegic patients. Archives of Physical Medicine and Rehabilitation, 1962, 43, 552-5. (b)

Ayres, A. J. Southern California Figure-Ground Visual Perception Test, Manual. Los Angeles, California: Western Psychological Services, 1966.

Bardach, J. L. Psychological factors in hemiplegia. Journal of the American Physical Therapy Association, 1963, 43, 792-797.

Bardach, J. L. Psychological factors affecting driving behavior in the disabled. Medical Clinics of North America, 1969, 53, 692-696.

Bardach, J. L. Psychological factors in the handicapped driver. Archives of Physical Medicine and Rehabilitation, 1971, 52, 328-332.

Bardach, J. L. Psychological considerations in hemiplegia. In Cobb, B. (Ed.) Medical and Psychological Aspects of Disability. Springfield, Ill.: Thomas, 1973.

Bennett, G. K., Seashore, H. G., and Wesman, A. G. Abstract reasoning, Form A: A subtest of differential aptitude test. New York: Psychological Corporation, 1947.

Birch, H. G., Proctor, F., Bortner, M., and Lowenthal, M. Perception in hemiplegia. I. Judgment of vertical and horizontal by hemiplegic patients. Archives of Physical Medicine and Rehabilitation, 1960, 41, 19-27.

Birch, H. G., Belmont, I., Reilly, T., and Belmont, L. Visual verticality in hemiplegia. Archives of Neurology, 1961, 5, 444-453.

Blakemore, C. B., and M. A. Falconer. Long-term effects of anterior temporal lobectomy on certain cognitive functions. Journal of Neurology, Neurosurgery, and Psychiatry, 1967, 30, 364-367.

Blakemore, C., Iverson, S. D., and Zangwill, O. L. Brain functions. In P. H. Mussen and M. R. Rosenzweig (Eds.), Annual review of psychology, Vol. 13. Pala Alto, California: Annual Reviews, 1972.

Bogen, J. E., The other side of the brain. I: Dysgraphia and dyscopia following cerebral commissurotomy. Bulletin of the Los Angeles Neurological Societies, 1969, 34, 73-105.

Bogen, J. E., and Gazzaniga, M. S. Cerebral commissurotomy in man. Minor hemisphere dominance for certain visuospatial functions. Journal of Neurosurgery, 1965, 23, 394-399.

Broadbent, D. E. Decision and stress. New York: Academic Press, 1971.

Broadbent, D. E., and Gregory. Accuracy of recognition for speech presented to the right and left ears. Quarterly Journal of Experimental Psychology, 1964, 16, 359-60.

Bruell, J. H., Peszczynski, M., and Albee, G. W. Disturbance of perception of verticality in patients with hemiplegia. Archives of Physical Medicine and Rehabilitation, 1956, 37, 677-681.

Bruell, J. M., Peszczynski, M., and Vok, D. Disturbance of perception of verticality in patients with hemiplegia: Second Report. Archives of Physical Medicine and Rehabilitation, 1957, 38, 776-780.

Bryden, M. P. Tachistoscopic recognition, handedness, and cerebral dominance. Neuropsychologia, 1965, 3, 1-8.

Bryden, M. P. Left-right differences in tachistoscopic recognition: Directional scanning or cerebral dominance? Perceptual and Motor Skills, 1966, 23, 1127-1134.

Bryden, M. P. An evaluation of some models of dichotic listening. Acta Oto-Laryngologica, 1967, 63, 595-604.

Bryden, M. P. Binaural competition and division of attention as determinants of the laterality effect in dichotic listening. Canadian Journal of Psychology, 1969, 23, 2, 101-13.

Buros, O. K. (Ed.), The seventh mental measurements yearbook. Highland Park, New Jersey: The Gryphon Press, 1972.

Buros, O. K. (Ed.), Test in Print II. Highland Park, New Jersey: The Gryphon Press, 1974.

Carmon, A., and Bechtoldt, H. P. Dominance of the right cerebral hemisphere for stereopsis. Neuropsychologia, 1969, 7, 29-39.

Chaney, R. B., and Webster, J. C. Information in certain multidimensional signals. U.S. Navy Electron Laboratory Report No. 1339, San Diego, California, 1965.

Chun, K. T., Cobb, S., and French, J. R. P. Measures for psychological assessment. Ann Arbor, Michigan: Survey Research Center of the Institute for Social Research, University of Michigan, 1975.

Cohen, G. Comment on "Information Processing in the Cerebral Hemispheres: Selective Activation and Capacity Limitations," by Hellige, Cox and Litvac. Journal of Experimental Psychology: General, 1979, 108, 309-315.

Cohen, L. Perception of reversible figures after brain injury. Archives of Neurology and Psychiatry, 1959, 81, 765-75.

Colarusso, R. P., and Hammill, D. D. Motor-Free Visual Perception Test, Manual. Novato, California: Academic Therapy Publications, 1972.

Corsi, P. M. Human Memory and the Medial Temporal Region of the Brain. Unpublished Ph.D. thesis, McGill University, 1972.

Crancer, A., and McMurray, L. Accident and violation rates of Washington's medically restricted drivers. Journal of American Medical Association, 1968, 205, 272-276.

Critchley, M. Speech and speech-loss in relation to the duality of the brain. In V. B. Mountcastle (Ed.), Interhemispheric relations and cerebral dominance. Baltimore, Md.: Johns Hopkins Press, 1962.

Curry, F. K. W. A comparison of left-handed and right-handed subjects on verbal and non-verbal dichotic listening tasks. Cortex, 1967, 3, 343-52.

De Cencio, D. V., Leshner, M., Voron, D. Verticality perception and ambulation in hemiplegia. Archives of Physical Medicine and Rehabilitation, 1970, 51, 105-110.

Dee, H. L., and Fontenot, D. J. Cerebral dominance and lateral differences in perception and memory. Neuropsychologia, 1973, 11, 167-173.

DeRenzi, E., Faglioni, P., and Spinnler, H. The performance of patients with unilateral brain damage on face recognition tasks. Cortex, 1968, 4, 17-34.

DeRenzi , E., Scotti, G., and Spinnler, H. Perceptual and associative disorders of visual recognition. Neurology, 1969, 19, 634-642.

Diller, L., and Weinberg, J. W. Bender gestalt test distortions in hemiplegia. Perceptual and Motor Skills, 1965, 20, 1313-1323.

Dimond, S. The double brain. Edinburg, U. K.: Churchill Livingstone, 1972.

Dimond, S. J., and Beaumont, J. G. (Eds.) Hemisphere function in the human brain. London: Elek Science, 1974.

Dolphin, J. E. & Cruickshank, W. M. The figure-background relationship in children with cerebral palsy. Journal of Clinical Psychology, 1951, 7, 228-231.

Domey, R. G., and Duckworth, J. E. Comparative study of highway accidents among 625 physically impaired licensees, matched with 625 non-impaired licensees. Harvard School of Public Health, Boston, Massachusetts, 1963.

Draper, N. R., and Smith. H. Applied regression analysis. New York: Wiley, 1966.

Dreyer, D. R. Physically handicapped drivers. State of California, Department of Motor Vehicles, Research Report 42, May 1973.

Ettlinger, G. The description and interpretation of pictures in cases of brain lesion. Journal of Mental Science, 1960, 106, 1337-46.

Faglioni, P., Scotti, G., and Spinnler, H. Impaired recognition of written letters following unilateral hemisphere damage. Cortex, 1969, 5, 120-133.

Faglioni, P., Spinnler, H., and Vignolo, L. A. Contrasting behavior of right and left hemisphere damaged patients on a discrimination and semantic task of auditory recognition. Cortex, 1970, 5, 366-398.

Gazzaniga, M. S. Some effects of cerebral commissurotomy on monkey and man. Ph.D. Thesis, California Institute of Technology, Pasadena, California, 1965.

Gazzaniga, M. S. The Bisected Brain. New York: Appleton-Century-Crofts, 1970.

Gazzaniga, M. S., and Sperry, R. W. Language after section of the cerebral commissures. Brain, 1967, 90, 131-148.

Geffen, G., Bradshaw, J. L., and Wallace, G. Interhemispheric effects on reaction time to verbal and nonverbal visual stimuli. Journal of Experimental Psychology, 1971, 87, 415-422.

Geffen, G., Bradshaw, J. L., and Nettleton, N. C. Hemispheric asymmetry. Verbal and spatial encoding of visual stimuli. Journal of Experimental Psychology, 1972, 95, 25-31.

Gainotti, G., and Tiacci, C. The relationships between disorders of visual perception and unilateral spatial neglect. Neuropsychologia, 1971, 9, 451-458.

Goldstein, L. G. Human variables in traffic accidents. A digest of research. Traffic Safety Research Review, 1964, 8, 26-31.

Goodglass, H., and Kaplan, E. The assessment of aphasia and related disorders: Boston diagnostic aphasic examination. Philadelphia, Pennsylvania: Lea and Febiger, 1972.

Gurgold, G. D., and Harden, D. H. Assessing the driving potential of the handicapped. American Journal of Occupational Therapy, 1978, 32(1), 41-46.

Hannay, H. J., and Malone, D. R. Visual field effects and short-term memory for verbal material. Neuropsychologia, 1976, 14, 203-209.

Harrower, H. R. Changes in figure-ground perception of patients with cortical lesions. British Journal of Psychology, 1939, 30, 47-51.

Hécaen, H. Clinical symptomatology in right and left hemispheric lesions. In Interhemispheric Relations and Cerebral Dominance, V. B. Mountcastle, ed. Baltimore: The Johns Hopkins Press, 1962, 215-243.

Henderson, R. L., and Burg, A. Vision and audition in driving. System Development Corporation, Santa Monica, California, November 1974.

Hilliard, R. D. Hemispheric laterality effects on a facial recognition task in normal subjects. Cortex, 1973, 9, 246-258.

Hines, D., Satz, P., and Clementino, T. Perceptual and memory components for the superior recall of letters from the right visual half-fields. Neuropsychologia, 1973, 11, 175-180.

Hulicka, I., and Beckstein, L. Perception of the vertical by hemiplegic patients. American Journal of Physical Medicine, 1961, 40, 192-200.

Isseroff, A., Carmon, A., and Nachshon, I. Dissociation of hemifield reaction time differences from verbal stimulus directionality. Journal of Experimental Psychology, 1974, 103, 145-149.

Jones, M. H. Driver performance measures for the safe performance curriculum. University of Southern California, Los Angeles, California, Technical Report 78-3, March 1978.

Kim, Y. C. Deficits in temporal sequencing of verbal material: The effect of laterality of lesion. Brain and Language, 1976, 3, 507-515.

Kimura, D. Some effects of temporal lobe damage on auditory perception. Canadian Journal of Psychology, 1961, 15, 156-65.

Kimura, D. Right temporal-lobe damage. Archives of Neurology, 1963, 8, 264-271.

Kimura, D. Left-right differences in the perception of melodies. Quarterly Journal of Experimental Psychology, 1964, 16, 355-358.

Kimura, D. Dual functional asymmetry of the brain in visual perception. Neuropsychologia, 1966, 4, 275-285.

Kinsbourne, M. (Ed.), Assymmetrical functions of the brain. Cambridge, U.K.: Cambridge University Press, 1978.

Kinsbourne, M., and Smith, W. L. (Eds.), Hemispheric disconnection and cerebral function. Springfield, Illinois: Charles C. Thomas, 1974.

Klingberg, C. L. Driving records of operators of hand controlled vehicles. Department of Licensing, Research and Technology Division, Olympia, Washington, Research Memorandum 7804, January 1979.

Lansdell, J. Effect of extent of temporal lobe ablations on two lateralized deficits. Physiology and Behavior, 1968, 3, 271-73.

Levy, J., and Trevarthen, C. Metacontrol of hemispheric function in human split-brain patients. Journal of Experimental Psychology: Human Perception and Performance, 1976, 2, 299-312.

Levy-Agresti, J., and Sperry, R. W. Differential perceptual capacities in major and minor hemispheres. Proceedings of the National Academy of Sciences, 1968, 61, 1151.

Lezak, M. D. Neuropsychological assessment. Oxford, U.K.: Oxford University Press, 1976.

McKeever, W. F., and Gill, K. M. Interhemispheric transfer time for visual stimulus information varies as a function of the retinal locus of stimulation. Psychonomic Science, 1972, 26, 308-310. (a)

McKeever, W. F., and Gill, K. M. Visual half-field differences in masking effects for sequential letter stimuli in the right and left handed. Neuropsychologia, 1972, 10, 111-117. (b)

Meier, M. J., and Thomas, R. University of Minnesota Hospital, Neuropsychology Laboratory Manual, unpublished manuscript, University of Minnesota, 1976.

Meyer, V., and Yates, H. J. Intellectual changes following temporal lobectomy for psychomotor epilepsy. Journal of Neurology, Neurosurgery, and Psychiatry, 1955, 18, 44-52.

Milner, B. Brain mechanisms suggested by studies of the temporal lobes. In: Brain Mechanisms Underlying Speech and Language, F. L. Darley, ed. New York: Grune and Stratton, 1967.

Milner, B. Visual recognition and recall after right temporal-lobe excision in man. Neuropsychologia, 1968, 6, 191-209.

Milner, B. Interhemispheric differences in the localization of psychological processes in man. British Medical Bulletin, 1971, 27, 272-277.

Milner, B. (Ed.), Hemispheric specialization and interaction. Cambridge, Massachusetts: The MIT Press, 1975.

Moscovitch, M., Scullion, D., and Christie, D. Early versus later stages of processing and their relation to functional hemispheric assymetries in face recognition. Journal of Experimental Psychology, Human Perception and Performance, 1976, 2, 401-416.

Mountcastle, V. B. (Ed.), Interhemispheric relations and cerebral dominance. Baltimore: The Johns Hopkins Press, 1962.

Murphy, E. H., and Venables, P. H. The investigation of ear asymmetry by simple and disjunctive reaction time tasks. Perception and Psychophysics, 1970, 8, 104-106.

Nebes, R. D. Perception of spatial relationships by the right and left hemispheres of commissurotomized man. Neuropsychologia, 1973, 11, 285-289.

Nebes, R. D. Dominance of the minor hemisphere in commissurotomized man for the perception of part-whole relationships. In M. Kinsbourne and W. L. Smith (Eds.), Hemispheric disconnection and cerebral function, Springfield, Illinois: Charles C. Thomas, 1974.

Negri, D. G., and Ibison, R. Accidents involving handicapped drivers. Journal of Traffic Medicine, 1979, 7, 23-26.

Oltman, P. K. A portable road-and-frame apparatus. Perceptual and Motor Skills, 1968, 26, 503-506.

Polich, J. M. Hemispheric differences in stimulus identification. Perception and Psychophysics, 1978, 24, 49-57.

Porteus, S. D. Porteus Maze, Vineland Revision. New York: Psychological Corporation, 1933.

Porteus, S. D. The maze test and clinical psychology. Palo Alto, California: Pacific Books, 1959.

Riddle, M., and Roberts, A. H. The Porteus Mazes: A critical evaluation. Research laboratories of the Department of Psychiatry, University of Minnesota, Report Number PR-74-3, 1974.

Rizzolatti, G., Umilta, C., and Berlucchi, G. Opposite superiorities of the right and left cerebral hemispheres in discrimminative reaction time to physiognomical and alphabetical material. Brain, 1971, 94, 431-442.

Russell, E. W. WAIS factor analysis with brain-damaged subjects using criterion measures. Journal of Consulting and Clinical Psychology, 1972, 39, 133-139.

Schlesinger, L. E. Human factors in driver training and education. In T. W. Forbes (Ed.) Human Factors in Highway Traffic Safety Research. New York: Wiley and Sons, 1972.

Shinar, D. Psychology on the road. New York: Wiley and Sons, 1978.

Smith, A. The symbol-digit modalities test: A neuro-psychologic test of learning and other cerebral disorders. In J. Helmuth (Ed.), Learning Disorders. Seattle: Special Child Publications, 1968, 83-91.

Smith, A. Nondominant hemispherectomy. Neurology, 1969, 19, 442-445.

Smith, A. Objective indices of severity of chronic aphasia in stroke patients. Journal of Speech and Hearing Disorders, 1971, 36, 167-207.

Smith, A. Dominant and nondominant hemispherectomy. In W. L. Smith (Ed.), Drugs, Development and Cerebral Function. Springfield: Charles C. Thomas, 1972.

Smith, A. Symbol Digit Modalities Test, Manual. Los Angeles, California: Western Psychological Services, 1973.

Sperry, R. W. Lateral specialization in the surgically separated hemispheres. In B. Milner (Ed.), Hemispheric specialization and interaction. Cambridge, Massachussetts: The MIT Press, 1975.

Springer, S. Ear asymmetry in a dichotic detection task. Perception and Psychophysics, 1971, 10, 239-41.

Sullivan, R. A., Celikyol, F., and Commaroto, L. Pre-driving evaluation for the brain-damaged patient. Mimeographed Report, Kessler Institute for Rehabilitation, West Orange, New Jersey, 1973.

Warrington, E. K., and James, M. Disorders of visual perception in patients with localized cerebral lesions. Neuropsychologia, 1967, 5, 253-266.

Wechsler, D. Manual for the Wechsler Adult Intelligence Scale. New York: Psychological Corporation, 1955.

Witkin, H. A., and Asch, S.E. Studies in space perception: IV. Further experiments in perception of the upright with displaced visual fields. Journal of Experimental Psychology, 1948, 38, 762-782.

Witkin, H. A., Dyk, R. B., Faterson, H. F., Goodenough, D. R., and Karp, S. A. Psychological Differentiation. New York: Wiley and Sons, 1962.

Wood, N. E. Comparison of right hemiplegics with left hemiplegics in visual perception. Journal of Clinical Psychology, 1955, 11, 378-380.

Worral, N., and Coles, P. Visual field differences in recognizing letters. Perception and Psychophysics, 1976, 20, 21-24.

Young, A. W., and Ellis, H. D. An experimental investigation of developmental differences in ability to recognize faces presented to the left and right cerebral hemispheres. Neuropsychologia, 1976, 14, 495-498.

Ysander, L. The safety of physically disabled drivers. British Journal of Industrial Medicine, 1966, 23, 173-180.

Zangwill, O. L. Cerebral Dominance and Its Relation to Psychological Function. Edinburgh: Oliver and Boyd, 1960.

Zangwill, O. L. Asymmetry of cerebral function. In Garland, H. (Ed.), Scientific Aspects of Neurology. London: E. and S. Livingstone, 1961.

Zimmerman, I. L., and Woo-Sam, J. M. Clinical Interpretation of the Wechsler Adult Intelligence Scale. New York: Grune and Stratton, 1973.

APPENDIX A

SUBJECT CONSENT FORM

SUBJECT CONSENT FORM

The purpose of this study is to compare performance on certain problem solving abilities in the laboratory with performance while driving an automobile. You will be asked to participate in both parts of the study.

One part will require you to do a number of tasks and answer questions. These are the type of tasks and problems which require written or oral responses and they will be given to you in private by an experienced test administrator. These tasks will measure your performance on many different problem solving abilities. Some will be very easy and some will be quite challenging. This part will require about three hours and may be split up into several sessions depending on when you can find time in your schedule.

In the other part of the study you will drive a car and we will ask you to carry out certain maneuvers. There is always the possibility of injury from an accident when driving an automobile, however, every precaution will be taken to minimize the risk of injury. A dual control car will be used and you will be accompanied by an experienced driver trainer. The drive will begin on a large vacant lot. If you are able to do well there, you will be asked to follow a course on the public streets. This part of the study will require about one hour. You will first be asked to have your vision checked. If you meet our research requirements, you will be asked to participate in the rest of the study. Those who will not continue after the vision test will be given $5 for their willingness and cooperation.

If, at any time, and for any reason, you prefer not to continue the study, you may withdraw from the study without prejudice either from the investigators or any persons or agency which may have referred you to us. You will be paid $25 upon completion of both parts of the study. In addition to the money, you may benefit from the study by gaining a better understanding of your own abilities.

All information and answers we collect from you will be kept strictly confidential. Under no circumstances will any of the individual's personal data be identified and used during the process of data analysis or in the write-up of results. The information and data about you as an individual will not be released to anyone unless you specifically give us written permission to do so. Please feel free to ask any questions about the study at any time.

I have read and understand the information presented above. My participation in this study is entirely voluntary.

Signature	Date
Witness	Date

APPENDIX B

RATING FORM FOR THE DRIVING EVALUATION BY THE DRIVER EDUCATOR

Overall Evaluation: Driving Potential

1	2	3	4
No	Possibly, with lots of training	Yes, with some training	Yes

Overall Evaluation: Psychomotor (Performance) Skills

1	2	3	4
Very Poor	Poor	Good	Very Good

Overall Evaluation: Perceptual and Cognitive Skills

1	2	3	4
Very Poor	Poor	Good	Very Good

Subject ______________________________

Date ________________________________