Acquired Brain Damage and Driving: A Review

A.H. van Zomeren, PhD

Department of Neuropsychology, University Hospital, 9713 EZ Groningen, The Netherlands

W.H. Brouwer, PhD

Department of Clinical Psychology, State University of Groningen, The Netherlands

J.M. Minderhoud, MD

Department of Neurology, University Hospital, 9713 EZ Groningen, The Netherlands

ABSTRACT. van Zomeren AH, Brouwer WH, Minderhoud JM: Acquired brain damage and driving: review. Arch Phys Med Rehabil 68:697–705, 1987.

● *Five issues in evaluating driving ability after brain damage were addressed through a review of the literature. Some preliminary conclusions were reached: (1) about half of all subjects studied still hold a valid driver's license; (2) brain-damaged drivers could not, in general, be seen as risky drivers, although some individuals show decreased driving skill and risky behavior in traffic; and (3) statistics show no increase in traffic violations or accidents in groups of neurologic patients with acquired brain lesions or diseases. Frequently noted problems of brain-damaged drivers include poor judgment of traffic situations, impulsivity, and visuospatial impairments. Traditional psychologic tests have insufficient predictive value regarding fitness to drive. It is suggested that new techniques be developed to enable more valid statements about the skills needed for safe traffic participation. These assessment techniques should emphasize the higher cognitive levels in driving, ie, the tactical and strategic levels. At the moment, driver training programs in rehabilitation focus mainly on the operational level, with emphasis on handling the car, use of controls and mirrors, and technical adaptation of the vehicle.*

KEY WORDS: Brain damage; Driver training; Driving; Traffic

Many people who experience some type of cerebral damage recover to an extent that makes them independent again in activities of daily living (ADL). In our highly motorized Western society, driving is almost regarded as another ADL. Patients who have recovered from a cerebrovascular accident (CVA) or severe head injury will, at some point during convalescence, ask their doctors or relatives whether they can resume driving. This simple question is hard to answer.

It has been generally assumed that brain damage can make a person unfit to participate in traffic. Driving a car requires a set of complex skills and abilities that may be impaired by cerebral lesions and diseases. In many countries a medical examination is required before a driver's license can be renewed after brain damage has been sustained. The *Centraal Bureau Rijvaardigheidsbewijzen* (CBR), the state office issuing drivers' licenses in the Netherlands, gives directives to physicians who judge driving fitness of individuals with physical and/or mental impairments.[25] In the subgroup of patients who have survived a severe head injury, a candidate is unfit to drive if, to a considerable degree, the following symptoms are noted: (1) increased irritability, impulsiveness, and aggressiveness, (2) poor concentration, (3) increased fatigability, (4) poor memory, and (5) personality changes resulting in antisocial behavior.

Since "considerable degree" is a vague measurement, the physician or neurologist often seeks a second opinion from a specialist in a related discipline, such as psychiatry or psychology. In fact, in most countries the problem of fitness to drive is examined by multidisciplinary teams, but even with the combined know-how of different professionals the decision often remains difficult. Which impairments result in deficient driving, and the relative importance of each impairment, are unknown.

METHOD

This review describes the available information about automobile driving by people with various kinds of acquired brain damage. It has been structured around the following five questions: (1) What proportion of patients with acquired cerebral damage continues or resumes driving a car? (2) Is this group of patients at high risk? (3) Is there a specific pattern of impairments that increases risk? (4) Can driving fitness be predicted from test performance? (5) Can driving skills be trained or retrained in this group?

DISCUSSION

Proportion of Licensed Drivers Among Subjects with Cerebral Damage

Seven investigators presented data on large groups of subjects with brain damage of various etiologies. The first of these[6] concerned 309 World War II veterans whose socioeconomic rehabilitation was studied 15 years after injury. Nearly all subjects had sustained penetrating missile injuries. At the time of follow-up, 200 subjects were active, licensed drivers. Although no information about age of subjects is given, it is reasonable to assume that 15 years after combat, mean age must have been between 30 and 45 years. Bijkerk and associates[2] studied the social outcome of 84 civilian subjects who had sustained moderate to very severe cerebral concussions by blunt head injury. They found that 66 (78%) of these patients were driving at the time of follow-up. When the sample was divided

66/84

Submitted for publication November 3, 1986 and accepted February 3, 1987.

by severity of injury, as measured by duration of posttraumatic amnesia (PTA), the results suggested a relation between severity of injury and licensed driving. In the subgroup of patients with a PTA of seven days or less, 88% were licensed, which is almost equal to the proportion of licensed drivers in the total Dutch population of a comparable age. In the subgroup of patients who had sustained severe to very severe concussions, with duration of PTA exceeding one week, 74% were licensed drivers.

Four reports concerning populations from rehabilitation centers have been published. Koops and coworkers[13] studied 50 subjects about five years after they sustained severe closed head injuries. These patients had PTA for an average of 62 days, and had been treated in a rehabilitation center after discharge from hospital. At the time of follow-up, their mean age was 28.3 years. Of these 50 subjects, 22 drove, and ten had acquired their licenses after discharge from the rehabilitation center. Hopewell and Price[10] reported on a group of 56 subjects who were treated at a rehabilitation center after sustaining closed head injuries. Their mean age at the time of the investigation was 25.3 years, and mean duration of PTA had been 68 days. Six months after discharge, 27 patients were engaged in independent operation of a motor vehicle. The original group of 56 subjects had, however, been previously selected for the driver training programs because they had achieved a final level of "moderate" or "good" recovery on the Glasgow Outcome Scale.[11]

Shore and colleagues[28] described a group of subjects who underwent training in a handicapped driver's education program at a rehabilitation institute. In a group of 200 neurologically impaired patients, primarily with CVA, cerebral palsy, and closed head injury, the relicensing rate was 50%. Quigley and De Lisa[23] reported on a group of 50 rehabilitation subjects with CVA who underwent training. Of these patients, 31 were relicensed. The authors noted a different relicensing rate for patients with CVAs in left and right hemisphere; 74% of the patients with CVAs in the left hemisphere passed the test, in contrast to 52% of the patients with CVAs in the right hemisphere. Ritter and Steinberg[26] studied 359 patients with Parkinsonism, and found that 156 still had drivers' licenses, although a number of them had voluntarily abandoned driving.

These studies suggest a few preliminary conclusions. About half the patients with acquired brain damage have licenses, but not every licensed driver actually drives. Lower percentages of licensed drivers are found in populations that were treated at rehabilitation centers, which suggests a relationship between severity of acquired brain damage and inability to drive. This relationship is also indicated by the differences noted by Bijkerk[2] between subgroups with moderate versus severe and very severe cerebral concussions. Parkinson patients are a special case. Their mean age, although not specified, must have been well over 50 years. In Europe, in this age group, about 60% of the total population are licensed drivers. Next, Parkinson disease is slowly progressive, whereas patients in the other groups suffered acute brain damage. All patients in the first six studies must have shown some degree of recovery, and in some of the cases with penetrating missile injury or moderate cerebral concussion, this recovery may have been almost complete.

Brain-damaged Patients as a High-risk Group

Half the patients studied still had the formal right to drive. Do they present a greater risk, both to themselves and to other road users? No clear answer to this question is available. Statistical studies of the relationship between diseases and traffic accidents have used very broad categories. For example, in a category "nervous and mental diseases" one finds a heterogeneous company of psychopaths, people with spinal cord lesions, and Parkinson patients. Statistics about accidents and traffic violations in such a group tell little about the specific category that this review is concerned with—drivers with acquired cerebral damage.

The literature on handicap and driving does suggest one firm conclusion. Several large-scale studies make it clear that physical handicaps *per se* are not related to an increased accident or violation rate. Michon points out "the policies of insurance companies who tend to consider handicaps of limbs and motility as good risks."[20] These policies have an empirical basis. McFarland and associates[17] reported in 1968 that there was no evidence of an increased accident rate in orthopedically handicapped drivers, ie, drivers with amputations. In addition, handicapped subjects were more strongly motivated to be good drivers than nonhandicapped. In 1973, the California Department of Motor Vehicles also failed to find an increased accident rate in men and women drivers with loss, or restricted use, of limbs.[5] A Swiss study of 187 one-eyed drivers[33] found that this group had fewer recorded accidents and violations than a control group, although the differences were not statistically significant. The data suggest that people with a serious physical handicap can compensate, in many cases, for their instrumental shortcomings.

Very few comparable studies of patients with cerebral damage have been published. In the Federal Republic of Germany all traffic accidents and observed violations are centrally recorded by the *Kraftfahrtbundesamt* (the State Motor Vehicle Department) in Flensburg. Investigators from the University of Göttingen have studied the records of samples of neurologic patients with brain tumors and Parkinsonism. Woldert and Ritter[35] reported on 101 patients with brain tumors who had drivers' licenses. Although this group was underrepresented in the central register, registrations from the patients were more often connected with severe accidents. Only patients with tumors of the hypophysis and with neurinoma, however, had a higher accident rate than the general population. This may indicate that even within a narrow neurologic category, general statements are unwarranted. Ritter[26] described a group of 156 patients with Parkinsonism, and reported that these subjects were also recorded less frequently in the federal register. They assumed that this underrepresentation is in part due to members of their patient group who voluntarily refrained from driving.

Sivak and coworkers[30] investigated driving skills in a group of 23 patients with brain damage, comparing them to patients with spinal cord damage and able-bodied subjects. Thirteen subjects experienced stroke, seven had traumatic head injury, and three had cerebral palsy. All subjects were tested with a set of driving tasks in a parking lot, and then in traffic over a fixed route through Ann Arbor, Michigan. The brain-damaged subjects performed significantly worse than the control group and the spinal cord patients on tracking tasks in the parking lot. Two were excluded from driving in traffic because it seemed too risky. Two other brain-damaged subjects were tested on the open road for only a few minutes because their driving was judged unsafe. Thus, 19 of the 23 subjects with brain damage finished the driving test. Four of the 23 brain-damaged patients were excluded from actual driving in an early stage, while the remainder of the group performed worse than control groups on a composite index comprising speed adaptation, observation of traffic scenes at junctions, etc. This group of mixed neurologic etiology was, to some extent, a high-risk group in actual traffic.

There is another category of studies that suggests increased risk in brain-damaged drivers. In studies of patients with CVAs who underwent driver training at rehabilitation centers,[1,23,28] a proportion of the trainees had to be excluded from actual driving because of poor planning and judgment, incautious behavior, etc. Both Bardach[1] and Quigley[23] noted that patients with CVA in the right hemisphere demonstrated poorer driving skills and were more difficult to train than patients with CVA in the left hemisphere.

In summary, statistical studies of accident and traffic violation rates reveal that people with cerebral damage should not, in general, be considered a high-risk group. An increased accident rate was observed only in subjects with neurinoma and tumors of the hypophysis. However, a detailed study of a small group—patients with CVA, cerebral palsy, and head injury—demonstrated poor driving skills, occasionally resulting in risky behavior. Furthermore, reports about driver training programs from rehabilitation institutes indicate that some trainees do not reach a level of safe driving. More specifically, patients with a cerebrovascular lesion in the right hemisphere often fail to pass the final test for relicensing.

Patterns of Errors

A few studies report on actual driving by subjects with acquired brain damage. Some of these are impressionistic, listing experiences with patients in clinical practice or in driver training programs at rehabilitation centers. Others are more systematic, using testing procedures and objective scoring methods for recording errors.

All findings will be discussed in terms of the Michon model of car driving.[19] Michon describes driving as a task with three levels in a hierarchic structure (table 1). On the top level, planning is an important aspect. Decisions are made about choice of route, time of day (avoiding rush hours), breaks, etc. Such decisions are usually made before actual driving starts, and include evaluating the general risks of traffic, conditions of traffic density, climate, and so on. Even the decision to take the train in preference to the car is a strategic one. At the tactical level, behavior and decisions in traffic are made: adapting one's speed when entering a residential district, switching on the headlights when rain reduces visibility, or deciding to pass another car. Finally, on the operational level, the common actions and decisions of driving are analyzed: perception of traffic situations, use of mirrors and controls, handling the car, and dealing with danger.

Table 1: The Hierarchical Model of Task Performance in Car Driving, as Presented by Michon (1979)

Level of task performance	Level of risk
Strategical	Accepting risk
Tactical	Taking risk
Operational	Dealing with acute danger

This three-level model is hierarchic in the sense that decisions on a higher level determine the working load on lower levels. For example, a tactical decision to pass requires a series of actions on the operational level. Another important feature is the increasing rôle of time pressure at descending levels. Time pressure is nearly zero at the strategic level, intermediate on the tactical level, but usually great on the operational level. To avoid dangerous situations, the actions on this level must be performed within a restricted time.

Strategic level. Information about impaired driving skills on the strategic level is scarce. To the best of our knowledge, no studies have been carried out on planning of trips or the selective use of cars by brain-damaged subjects, although several reports of driving behavior in people with acquired lesions indicate poor planning, poor judgment, and impulsivity.[1,10,23] Unfortunately, it cannot be deduced from these papers whether impaired insight has an effect on the strategic or tactical level. Since most of the reports dealt with actual driving, it should be assumed that the quoted characteristics were observed mainly at the lower task levels. It seems likely, however, that poor planning, poor judgment, and impulsivity influence strategic decisions as well.

Tactical level. Several investigators noted serious impairments in the driving of brain-damaged subjects on the tactical level. Their observations were all made during actual driving in retraining programs. Although driving instructors used standard observation schemes, not all aspects were scored in a purely objective way. For example, "approaching crossings too fast" is not an unambiguous observation, since the judgment is subjective and related to factors like traffic density, visibility, and the driver's visuomotor skills. The statements that were found in the literature are listed verbatim in table 2 to retain the original flavor for the reader.

Table 2: Impairments on the Tactical Level

Bardach, 1971	Disinhibition leading either to panic Reactions or marked impulsiveness In left hemiplegics: Poor planning Inability to shift according to Changing demands Poor judgment Reduced awareness of traffic conditions
Shore and coworkers, 1980	General reduction in cognitive control manifested as disinhibition distractibility impulsivity stimulus binding Rigidity
Quigley and DeLisa, 1983	Poor judgment Inability to perceive hazards Incautious behavior
Hopewell, 1985	Errors of judgment Impulsivity

Impulsivity and poor judgment are cited most frequently by investigators. Impulsivity is attributed to disinhibition or reduced cognitive control. Poor judgment is not defined in these studies, but it may be assumed that this characteristic is derived from poor estimation of risks and inadequate adaptation of speed to traffic conditions.

Operational level. The next question is whether brain-damaged drivers show impairments in basic driving skills such as controlling the vehicle, steering, perceiving, and taking action. A review of the literature indicates that investigators show little concern about motor deficits like hemiparesis. Obviously, this is due to the fact that technical adaptations of the vehicle, such as a steering wheel spinner knob or left-sided accelerator, can compensate for these motor weaknesses. Table 3 presents statements from the literature that seem to apply to driving at the operational level. For some quotations, it has been difficult to decide whether they were concerned with the tactical or the operational level, as the observations were phrased in general terms. Thus, there may exist some overlap between tables 2 and 3.

Although investigators describe a variety of impairments at the operational level, most fit into five general categories: inadequate visual scanning of traffic and environment, problems in spatial perception and orientation, poor tracking, slowness in acting, and confusion when more complex actions have to be carried out. Personal communication with the staff of a Dutch rehabilitation center[22] added two relevant observations. In their training program, these investigators noted poor tracking, as did many others. In addition, they noted problems resulting from poor coordination in the lower limbs. Their patients had difficulty in the subtle control of brake and accelerator. They were braking too brusquely and were unable to drive very slowly, as required in traffic jams. Finally, the driving instructor noted that some trainees were able to judge traffic adequately when riding a bicycle, but not when driving a car. In his view, "pictures are coming too fast" while driving.

Table 3: Impairments on the Operational Level

Bardach, 1971	Perceptual-motor problems Cognitive problems In left hemiplegics: Inadequate scanning of the environment Inability to shift according to changing demands Distractibility Confusion Confusion between right and left Inadequate use of space Ignorance of environment on the left side
Shore and coworkers, 1980	Slowed reaction time Attentional impersistence Visuospatial deficits
Quigley and DeLisa, 1983	Difficulty with low-complexity tasks, confusion at two-stage commands Drifting sideways by unilateral neglect Difficulty with sequencing procedures in starting and stopping Left-right confusion Inattentiveness to signs
Gurgold and Harden, 1978	Deficiencies in figure-ground perception, signs versus background Deficient perception of spatial relationships Deficient ocular pursuit Deficient horizontal perception
Sivak and coworkers, 1981	Poor tracking, both in straight lines and in S-curves Insufficient observation on turns (particularly left hemiplegics) Incautious gap acceptance when merging into traffic
Stokx, 1984	Significantly slower than controls in shifting gears, braking, and slalom driving
Hopewell, 1985	Severe motor retardation Severe visual perception problems like diplopia and visual field defects Topographical disorientation

Two studies seem to belong to a new generation of investigations. Both Sivak's group[30] and Stokx and Gaillard[31] studied small groups of brain-damaged subjects in an experimental design, and both reports stem from nonclinical research institutes. Both studies attempt to relate actual driving skills to psychometric or experimental test performance. The Sivak report was based on driving in traffic and closed-course driving, whereas Stokx considered closed-course driving only. Both investigators tested the ability to drive a straight course and a slalom, or 8-shaped course between lines of cones. They found that subjects needed significantly more time to finish the tracks, and knocked over more cones, than the controls. Stokx reported that his patient group took 71.8 seconds for the slalom, while the control group needed only 50 seconds. Shifting gears from a full stop up to the fourth gear took 20.9 seconds in the subject group, and 15.5 seconds in the control group, but the number of errors in shifting gears was almost equal in the two groups (1.7 and 1.8, respectively).

Side of lesion. Left hemiplegics are judged less favorably as drivers in several studies. Obviously, a lesion in the right hemisphere may result in deficits in skills that are crucial for driving, such as adequate visual scanning of the environment and adequate use of space. A particular problem is caused by the phenomenon of unilateral neglect, which is usually manifest on the left side of the patient's field of vision.[9]

To summarize briefly, no information is available about typical impairments of brain-damaged drivers at the strategic level. At the tactical level, poor judgment and impulsivity seem to be major sources of risk. On the operational level, a variety of deficits can be noted, but pure motor problems play a minor role. The greatest problem on this level seems to be in the visuospatial sphere, and in an inability to deal with complex situations that require rapid sequencing of responses. Finally, there is a strong suggestion that lesions in the right hemisphere are a greater threat to driving skills than left-sided lesions.

Predicting Fitness

It would seem reasonable to assume that fitness to drive can be predicted, to some extent, from clinical characteristics of a brain-damaged patient, and the medicolegal evaluation procedures quoted earlier are based on that assumption. Variables that might have some predictive value include severity of disease or injury, duration of illness, rate of progression in diseases like Alzheimer or Parkinson disease, age of the patient, and previous driving experience.

There is an impressive list of tests for the assessment of psychologic deficits in people with acquired brain damage.[15] Although this arsenal may have something to offer in assessing driving skills in brain-damaged subjects, little research has been done on the validity of neuropsychologic tests with regard to driving. Some tests would seem to have "face validity," like a test of visual reaction time (RT) or visual search. Unfortunately, such face validity does not always hold at closer inspection: at least in the healthy population, RT is not at all related to driver quality.[21] The efficient driver is not the one who reacts quickly, but the one who avoids situations in which only his fast reaction can save him from disaster. In this context, Hopewell[10] notes that drivers between the ages of 15 and 20 years, or those drivers who are at the peak of their psychomotor coordination, have the highest risk of accidents.[18] Similarly, elderly drivers are safe drivers, generally speaking, despite their increased RTs.[4]

Another methodologic problem is the external criterion for the concept of fitness to drive. How can we verify predictions about patients? An obvious criterion would be the number of accidents or traffic violations in, say, the first five years after relicensing or during the first 50,000 kilometers of driving. However, this index would be hard to come by, and then only a crude measure of someone's fitness to drive.

One might consider expert judgment of a patient's driving in real traffic. Clearly, this is an imperfect criterion, since subjects may drive cautiously in the company of a judge, and recklessly when alone. It is well known that the driver's examination used in most European countries gives no guarantee that one will drive safely ever after. On the other hand, this paper is concerned with the clinician's problem of judging fitness to drive: professionals in rehabilitation must decide whether a trainee is able to drive, but cannot be asked to guarantee that he will always use his abilities in an optimal way.[4]

One might also think of an external criterion as the opinion of a multidisciplinary team, including a driving instructor or examiner. However, even the combined know-how of several professionals does not guarantee predictive validity. For instance, they may tend to focus on the same technical and somatic problems of the applicant, or they may share the same prejudices about elderly drivers.

With these methodologic problems in mind, the available evidence on prediction of fitness to drive is presented. The literature on both clinical variables and psychologic tests is limited. Moreover, we have already seen that basic descriptive data on age of patients and duration of illness are often lacking in these reports.

Clinical variables. Golper and associates[7] studied a group of 20 aphasic adults, evaluating the ability of these patients to decide on their own fitness to drive. The sample consisted of ten patients who had resumed driving and ten patients who had decided not to drive. A comparison was then made of a rehabilitation team's assessment of driving skills and the patient's own judgments. The team based its decision on a variety of clinical ratings and tests, among them visual acuity and simple visual RT. A highly significant agreement was found ($p<.005$) between professional and patient judgment, suggesting that the aphasic subjects had appropriately judged their own competence to drive. In fact, four of the nondrivers were judged by the rehabilitation team as fit to drive, indicating that patients tended to be cautious in their decisions. All patients who had judged themselves fit to drive were also considered fit to drive by the professional team.

The degree of overall communicative impairment of these 20 subjects had been assessed with the Porch Index of Communicative Ability (PICA). There was no significant difference between drivers and nondrivers in overall severity of communication impairment demonstrated by the Mann-Whitney U-test. This suggests that degree of aphasia has no predictive value for fitness to drive. Neither age of the patient (ranging from 44 to 75 years) nor duration of illness had a relation to their fitness classification.

Discriminant analysis of variables tested by the team indicated that impairments in spatial relationships, motor function, sequencing, and peripheral vision, had the greatest weight in professional judgment. Reaction time contributed very little. Spatial relationships and motor functions also appeared as discriminating in the analysis of patient judgments, but aphasic subjects considered verbal expression and auditory comprehension as well. Subjects were more concerned about linguistic impairments than was the team—unjustly, as the PICA scores for the subgroups revealed. The outcome of this study is an agreement with the experience of Bardach,[1] who noted that verbal impairments of right hemiplegic individuals are not central to the task of driving.

In head-injured subjects, severity of injury might predict fitness to drive. In current research on head injury, duration of PTA is generally considered the best single index of severity. This index was recommended in 1961 by Russell, and propagated by the Glasgow group of head injury investigators.[3] Posttraumatic amnesia is defined as the interval from the moment of impact until the return of orientation and memory of daily events. For severe and very severe head injuries, duration of PTA is best expressed in number of days. Bijkerk[2] found fewer licensed drivers among patients whose PTA exceeded one week.

Hopewell[10] described a group of 56 severely head-injured subjects at a rehabilitation center who were candidates for a driver training program. Mean duration of PTA had been 68 days in this group. Six months after discharge from the center, 27 subjects were engaged in licensed driving. There was a significant difference in mean duration of PTA for drivers and nondrivers. In the first group, mean duration of PTA was 37 days, and in the latter group, 95 days (student t-test $p<.05$). These data suggest that even within a population of severely injured patients, duration of PTA has some predictive value.

Finally, as a broad and vague category of clinical variables, frontal symptoms are sometimes mentioned in relation to fitness to drive. In patients with severe head injury, lack of self-criticism is often observed and interpreted as a sign of damage to the frontal lobes, with negative implications for safe driving.[14] The literature indicates that poor judgment and impulsivity are often noted in brain-damaged drivers, and these characteristics suggest that the functions of the prefrontal lobes play an important role in driving.

Psychologic tests. Intelligence tests have been mentioned as predictors of fitness to drive. Maag[16] stated that an IQ below 70 makes a candidate unfit to drive. The usefulness of this statement is questionable, because it does not differentiate between feeble-minded persons and individuals of originally normal intelligence who have sustained extensive cerebral damage. Hopewell[10] found an average full-scale WAIS-IQ of 94.4 in the driving group, and 78.5 in the nondriving group. In fact, only one person with an IQ below 80 was able to achieve motor vehicle operation. This man had previously been a chauffeur. Although the difference between groups was highly significant (student t-test $p<.001$), the practical value of IQ as a predictor remains to be proven. For one thing, test scores on the performance part of the WAIS will often be lowered by the slowness that is characteristic of most brain-damaged patients.[34] In addition, full-scale IQ may be reduced by an effect of focal damage unrelated to driving skills. Aphasic individuals, for example, may perform poorly on the verbal part of the WAIS, but their aphasic impairments do not negatively affect their driving.[7] Since IQ tests usually investigate a wide range of cognitive abilities and visuomotor speed, the final IQ is merely a crude index of overall severity of brain damage. Further, IQ varies widely in a healthy population, with no apparent relation to driving skill, as judged by rate of accidents or traffic violations. IQ may be important only when it lies at the lower limit of the normal range. An IQ below 80 may have consequences for insight on the strategic and tactical levels of driving.

Predictive validity has been claimed for tests of visual RT and perception of complex patterns. Visual RT contributed to some extent in the discriminant analysis by Golper[7] when the investigators classified aphasic patients as fit or unfit to drive. Shore[28] noted slowed RT secondary to attentional impersistence in patients who failed to achieve relicensing. In two investigations, RT has been directly related to actual driving. Sivak[30] recorded two-choice RT in his group of 23 brain-damaged subjects, finding large differences in comparison to subjects with spinal cord damage and healthy controls. However, choice RT was not included in the psychologic test scores that yielded useful correlations (>.45) with the composite driving index based on a ride through town traffic. On the other hand, Ravestein and coworkers[24] found high correlations between choice RT and time required to drive a slalom on a closed course (coefficients ranging from .66 to .84), and time required for switching gears. Hence, a relation has been demonstrated between RT and efficiency in handling a car, expressed in speed of performance. It remains to be seen, however, what the meaning of this relation is for the broader concept of fitness to drive.

Tests of visual perception have been recommended as relevant to the judgment of driving fitness. According to Gurgold and Harden,[8] the Frostig Test of Visual Perception can detect a deficit in the ability to distinguish important foreground information, such as road signs or traffic lights, from insignificant background. They likewise attribute predictive value to the Space Visualization Test (included in the Southern California Sensory Integration Tests by A. Jean Ayres) and the Frostig Developmental Test of Visual Perception. However, which specific driving abilities are measured by the latter tests is not completely clear. The authors refer to faulty interpretation of angles, curves, cross roads and merging lanes, and inadequate ocular pursuit.

Quigley[23] reported experiences with CVA patients in a driver training course. He used parts of the Bender Gestalt Test to assess visual neglect, spatial disorganization, visual memory, and learning, all relevant to driving, as he added with an apparent belief in face validity. He also made use of the Trail-making Test A and B, that requires visuospatial search while using systems of letters and numbers. In the Sivak study cited earlier,[30] performance on two visual tests was clearly related to actual driving. Picture Completion from the Wechsler Adult Intelligence Scale correlated 0.72 with the Composite Driving Index, while Picture Arrangement from the same WAIS correlated 0.46 with the Index. A variety of other visual tests like the rod-and-frame test (setting a rod in a tilted frame to the vertical position) and the Porteus Maze (tracking a path through a printed maze) seemed to have little value in predicting driving skills. The usefulness of Picture Completion and Picture Arrangement was not confirmed by Ravestein,[24] who found no relation between these tests and the performance of head-injured patients in closed-course driving.

At first glance, a simulator with a realistic, dynamic presentation of traffic scenes would seem to be the best test of fitness to drive. Reports on simulator use with brain-damaged subjects are very limited. Quigley et al. report on the use of a simulator for a partial assessment of driving skills in younger CVA patients before in-car evaluations started. Although the simulator was judged useful for the evaluation of some driving skills, such as visual perception, laterality, and directionality skills, the report does not sound entirely positive, for example, when the author remarks that the cognitive tasks of following directions, sequencing, and learning new behaviors, may be "grossly assessed." Obviously, the authors are not entirely enthusiastic about a partial or gross assessment. Moreover, the simulator seemed useful for younger patients only.

Hopewell[10] also reports mixed feelings about the use of the same type of simulator. When comparing head-injured drivers and normal control subjects on simulator performance, the error scores barely differentiated between groups. Although overall scores differed significantly, almost all of the variance was accounted for by the score on an acceleration subtest. Simulator scores correlated poorly with expert judgments of actual driving in traffic.

An improved simulator would make high demands on technology, including a direct relationship between the subject's behavior and projected traffic scenes. In simple simulators, standard videotapes or films are used that proceed regardless of the subject's reactions, and tapes or films have focused on training of healthy subjects, rather than on groups with special needs.

To summarize this section, the question of predicting fitness to drive raises various methodologic problems, including the validity of tests and rating scales, and the need for external criteria. Empirical evidence on useful predictors is very limited. It has been demonstrated in a small group of aphasic patients that degree of aphasia, age, and duration of illness, had no relation to fitness to drive as judged by a multidisciplinary rehabilitation team. In patients who had sustained very severe closed head injuries, severity of injury as expressed in duration of PTA seemed to have some predictive value for relicensing. Frontal symptoms like lack of self-criticism and disinhibition have been mentioned by some authors as incompatible with safe driving. Overall IQ has been proposed as a predictor, but its usefulness is questionable because of the many factors (both premorbid and postmorbid) that determine the final IQ, and because of the fact that intelligence is not related to driving skills in the healthy population. Visual RT has a limited predictive value, according to some studies: RT in the laboratory predicts to some extent the speed of handling a car while maneuvering in a closed course. Various tests of visual perception, visual search, and visuospatial abilities have been proposed as predictors. For some tests, evidence of predictive value is conflicting. Others have been presented on the basis of their face validity only.

Finally, some experience has been reported with simulators in the selection and training of brain-damaged subjects in rehabilitation centers. The usefulness of these expensive and complicated instruments has not yet been demonstrated convincingly.

Training and/or Retraining

Many rehabilitation institutes have developed driver training courses for their disabled clients. These courses usually include both the theoretical and practical aspects of driving. Although most training programs are principally concerned with driving a car, in bicycling countries like the Netherlands and Denmark, bicycling is also trained at some centers. In addition, there are some reports about the training of brain-damaged pedestrians.[27]

Driver training courses at rehabilitation centers have very high success rates with patients with handicaps other than brain damage. Shore[28] reports a relicensing rate of 90% in patients who were impaired by spinal cord injury, congenital disability, and muscular dystrophy. Kent and associates[12] report a success rate of 92% in a group of mainly spinal cord injured patients. For subjects with brain damage, percentages of relicensing are much lower. In the training program mentioned above, Shore[28] found that 50% of patients with cognitive impairments due to CVA, cerebral palsy, and closed head injury, were relicensed. Quigley[23] reports a relicensing rate of 52% in patients who had CVAs. Hopewell[10] found that 53% of a group of severely head-injured patients were driving six months after discharge from a rehabilitation center where they had participated in a driver training program. These percentages seem to indicate that at least half the patients who sustain severe cerebral lesions can be retrained to an acceptable level of driving skills, but these data must be interpreted with caution, for two reasons. First, due to limitations in staff and time, only patients who appear to have a reasonable chance of success are admitted to the training programs. Success rates may be inflated by this selection mechanism. Second, there is no information available about comparable patient groups who did not participate in training or retraining courses.

Although not stated explicitly in the investigations, driver courses were obviously taken by patients of whom most were licensed before sustaining cerebral lesions. In other words, these reports are in fact concerned with the retraining of driving skills. It seems worthwhile to distinguish clearly, in future research, between training and retraining. At first sight, those trainees who have to relearn their former skills might have a lead when the more automatic acts of driving are preserved. On the other hand, in some cases these very automatisms may interfere with a learning program when the latter requires a drastic change in motor patterns. Postma and de Rijk[22] noted that right hemiplegics are hindered in their retraining by automatic reactions with the left leg. For example, when a subject tries to declutch in a training vehicle with automatic transmission, he may step abruptly on the accelerator pedal that has been placed on the left side. Unlearning automatic responses demands a flexibility that may be absent or reduced after severe cerebral lesions. The need to distinguish between training and retraining can be illustrated with data presented by Koops.[13] In groups comparable in severity of injury and age, a late follow-up found that the proportion of licensed drivers was far greater in the group who drove before injury. In this group, 60% had drivers' licenses at follow-up while only 33% were licensed drivers in the group who had not been driving before injury.

The designs of training programs seem to have much in common. Classroom instruction, technical handling of the car, maneuvering and actual driving in traffic figure in all courses. Still, the net effects of these training programs are difficult to compare from study to study, because the length and intensity of training is always adapted to the specific needs of a particular patient. In addition, the pattern of motor and cognitive impairments of trainees varies, as do the technical adaptations that are realized in the subject's own cars.[8] The possibilities of technical adaptation seem almost unlimited. Störig[32] describes technical equipment that enables even subjects without upper limbs to drive.

Most training courses emphasize driving skills on the operational level, like handling a car and maneuvering. In addition, during training in traffic, patients are also monitored on certain decisions and actions on the tactical level. For example, directions might be given on safely judging gaps in traffic when merging. It may be suggested that training programs for brain-damaged subjects should pay more attention to the strategic level of car driving. It might be useful to train subjects on selective and sensible uses of cars. On the tactical level, more emphasis could be placed on defensive and anticipatory driving.

All training programs have a practical orientation; they are not theoretical. This is fully understandable, considering the primary aim of rehabilitation and the client-centered approach of rehabilitation services. Moreover, this practical approach seems to work, as measured by relicensing rates. However, an interesting alternative has been described by Sivak and colleagues.[29] In a previous study,[30] some perceptual and cognitive impairments related to faulty driving in brain-damaged subjects were identified. The investigators then designed a perceptual training program for eight subjects with acquired brain damage. The program consisted of simple paper and pencil exercises during eight to ten hours of individualized training, requiring the use of a wide range of perceptual skills and abilities (visual scanning, directed eye-movements, spatial perception and discrimination, figure/ground differentiation, visual imagery, attentional capacity, and general problem-solving approach). This training was preceded and followed by repeated evaluations of perceptual skills and in-traffic driving performance.

The perceptual evalution was carried out with tests that were not used in the training sessions. Driving skills were evaluated on a 17-km course through light-to-moderate town traffic. Actions were scored in categories like safe gap acceptance in merging, speed, lane keeping, etc. The results indicated that perceptual skills improved after such training; the training was also associated with improved driving performance. The degree of driving performance improvement was directly related to the degree of improvement in perceptual skills. The authors concluded that their findings support training that deals with underlying component skills, not merely with the functional behaviors of interest.

Both the practical rehabilitation approach and training of underlying skills claim success. It remains to be seen whether one of these approaches will prevail or whether they can supplement each other to the benefit of the trainees.

CONCLUSION

Although the problem of judging fitness to drive is receiving increasing attention, few solid statements can be made, but some general conclusions are possible.

First, it is clear that brain-damaged subjects form a specific subgroup in the population of rehabilitation institutes, where driving fitness is concerned. Although success rates of retraining programs are strikingly high for the non-brain-damaged disabled, only half the population with cerebral lesions can be trained to an acceptable level of driving skill.

Second, brain-damaged subjects who resume driving cannot be described as a high-risk group. Although large-scale statistics are lacking, several studies indicate that subgroups of neurologic patients are not conspicuous for their number of traffic violations and accidents. In future research, it seems important to pay attention to variables of etiology, size of lesion, side of lesion, and interval since the beginning of the cerebral disease or the moment of injury. Two important distinctions might be focal vs diffuse lesions, and stable vs progressive lesions. Another informative variable could be driving experience before injury or disease. It would be of both theoretical and practical interest to find out whether overlearned skills are less vulnerable to brain damage than the skills of a less experienced driver.

Third, in the case of stable brain lesions, many patients seem able to compensate for their motor and cognitive deficits by adapting their driving style, by restricted use of their cars, and by the use of technical adaptations of the vehicle. The first two of these compensation mechanisms require awareness of one's deficits and impairments. Therefore, it is probable that compensation of psychologic deficits will be possible only in those brain-damaged drivers with preserved insight and self-criticism. This could mean that negative personality changes resulting from lesions in the frontal lobes are the most important causes of reduced driving skills and increased risk. A combination of serious instrumental shortcomings and lack of insight about these shortcomings will make a brain-damaged driver a danger on the road. Future research should therefore pay special attention to the topics of compensation and personality changes.

Acknowledgments: *We would like to thank the staff of the Foundation for Research on Traffic Safety, the SWOV in Leidschendam, who carried out a computer search of the literature, and who supplied data on drivers' licenses for the general Dutch population.*

ADDRESS REPRINT REQUESTS TO:
A.H. van Zomeren, PhD
Department of Neurology
University Hospital
9713 EZ Groningen
The Netherlands

References

1. Bardach JL: Psychological factors in handicapped driver. Arch Phys Med Rehabil 52:328–332, 1971
2. Bijkerk M, Brouwer WH, van Zomeren AH: Contusio cerebri - jarenlange kopzorgen? Internal report. Dept. of Clinical Psychology, State University, Groningen, 1986
3. Brooks DN: Memory and head injury. J Nerv Ment Dis 155:350–355, 1972
4. Brouwer WH: Bejaarden in het verkeer. *In*: Rothengatter JA, Michon JA (eds), Sociale Verkeerskunde, in press, 1987
5. California Department of Motor Vehicles: A study of the physically handicapped driver. May 1973
6. Erculei F: Socioeconomic rehabilitation of head-injured men. *In* Walker AE, Caveness WF, Critchley M (eds): Late Effects of Head Injury. Springfield, Thomas, 1969, pp 381–388
7. Golper LAC, Rau MT, Marshall RC: Aphasic adults and their decisions on driving: evaluation. Arch Phys Med Rehabil 61:34–40, 1980
8. Gurgold GD, Harden DH: Assessing driving potential of handicapped. Am J Occup Ther 32:41–46, 1978
9. Heilman KM, Watson RT: Mechanisms underlying unilateral neglect syndrome. Adv Neurol 18:93–106, 1977
10. Hopewell CA, Price RJ: Driving after head injury. J Clin Exp Neuropsych 7:148, 1985
11. Jennett B, Bond M: Assessment of outcome after severe brain damage: practical scale. Lancet 1:480–487, 1975
12. Kent H, Sheridan J, Wasko E, June C: Driver training program for disabled. Arch Phys Med Rehabil 60:273–276, 1979
13. Koops D, Deelman BG, Saan RJ: Het leven na een contusio cerebri onderzoek onder 50 traumapatienten. Internal report. Dept. of Neuropsychology, State University, Groningen, 1981
14. Lambrecht R: Möglichkeiten und Grenzen der Kompensation von Leistungsmangeln. Unfall- und Sicherheitsforschung Strassenverkehr, Heft 16, 136–143, 1978
15. Lezak MD: Neuropsychological assessment. Ed 2, New York, Oxford University Press, 1983
16. Maag F: Kann ein Schwerbehinderter ein Fahrzeug lenken? Unfall- und Sicherheitsforschung Strassenverkehr, Heft 51, 83–90, 1985
17. McFarland RA, Domey RG, Duggar BC, Crowley TJ, Stoudt HW: An evaluation of the ability of amputees to operate highway transport equipment. Harvard School of Public Health, Cambridge, 1968
18. McFarland RA, Moore RC, Warren AB: Human variables in motor vehicles accidents: a review of the literature. Harvard School of Public Health, Cambridge, 1954
19. Michon JA: Dealing with danger. Summary report of a workshop in the Traffic Research Centre, State University, Groningen, 1979
20. Michon JA: Medical screening of road-users in the Netherlands. Werkgroep Verkeerskunde, State University, Groningen, 1975
21. Mihal WL, Barrett GV: Individual differences in perceptual information processing and their relation to automobile accident involvement. J Appl Psychol 61:229–233, 1976
22. Postma W, de Rijk A: Personal communication, Heliomare Rehabilitation Centre, Wijk aan Zee, the Netherlands, 1985
23. Quigley FL, DeLisa JA: Assessing driving potential of cerebral vascular accident patients. Am J Occup Ther 37:474–478, 1983
24. Ravestein R, Veling IH, Gaillard AWK: De rijgeschiktheid van revalidanten met een diffuse hersenbeschadiging - een problee-

morientatie. Report nr. IZF 1982-16, Instituut voor Zintuigfysiologie, Soesterberg, 1982
25. Richtlijnen Geneeskundige CBR. Centraal Bureau voor afgifte van Rijvaardigheidsbewijzen, Rijswijk, the Netherlands, 1971
26. Ritter G, Steinberg H: Parkinsonismus und Fahrtauglichkeit. Muench Mediz Wochenschr **121**:1329–1330, 1979
27. Schuerman JA, Leurs M, Magné C: Een revalidatie alleen volgens medische weg is niet realistisch. Mensen op straat, 29–33, 1981
28. Shore D, Gurgold G, Robbins S: Handicapped driving: overview of assessment and training. Arch Phys Med Rehabil **61**:481, 1980
29. Sivak M, Hill CS, Henson DL, Butler BP, Silber SM, Olson PL: Improved driving performance following perceptual training in persons with brain damage. Arch Phys Med Rehabil **65**:163–167, 1984
30. Sivak M, Olson PL, Kewman DG, Won H, Henson DL: Driving and perceptual/cognitive skills: behavioral consequences of brain damage. Arch Phys Med Rehabil **62**:476–483, 1981
31. Stokx LC, Gaillard AWK: Task and driving performance of patients with severe concussion of brain. J Clin Exp Neuropsych **8**:421–436, 1986
32. Störig E: ueber die Eignung von Körperbehinderten zum Führen von Kraftfahrzeugen aus orthopädischer Sicht. Unfall- und Sicherheitsforschung Strassenverkehr, Heft 16, 1978
33. Thalmann H: Der Einäugige im Strassenverkehr. Schweiz Med Wochenschr **101**:981–987, 1971
34. Van Zomeren AH, Brouwer WH, Deelman BG: Attentional deficits: riddles of selectivity, speed and alertness. *In* Brooks DN (ed): Psychological, Social and Family Outcome of Severe Blunt Head Injuries. London, Oxford University Press, 1984, pp 74–107
35. Woldert M, Ritter G: Hirntumorkranke im Strassenverkehr. Nervenarzt **54**:304–310, 1983

☆