■ Special Lecture

Assessment and Rehabilitation of Driving Ability after Brain Damage

Wolfgang Hartje*

Abstract : The assessment and restoration of driving ability after brain damage has attracted increasing attention in neurological rehabilitation. It is now recognized that the ability to drive contributes essentially to the patients' rehabilitation by making them more independent and by supporting their social activities (not to mention those patients who need a driving licence for their job). In addition, the ability to drive seems to play an important role for the patients' self-esteem.

Relatively little is known, however, about how fit to drive brain-damaged patients actually are. A number of neurological symptoms clearly preclude driving, like for example the possible occurrence of epileptic seizures, the increased risk of re-insults after a stroke, the presence of large hemianopic field defects or of disintegrating disorders of limb movements or of a marked degenerative dementia. In the majority of brain-damaged patients, however, the ability to drive has to be judged from the results of various functional examinations, including neuropsychological measures. Detailed guidelines developed by a large board of medical experts and edited by the German Ministery of Traffic in order to help with the judgement of driving ability stress the importance of deficits of psychomotor, attentional, intellectual and mnemonic functions. The presence of functional deficits combined with a lack of insight into these deficits is seen as particularly disadvantageous and dangerous. However, apart from the recommendation of neurological, psychiatric and neuropsychological examinations, the guidelines do not give any clear suggestions on how these functional deficits are to be assessed, and the validity of the measures in question is obviously taken for granted.

Empirical studies comparing the results of neuropsychological assessment with the outcome of on-road driving tests reveal that the fitness to drive can not be reliably predicted from psychometric test results. Attempts to predict the outcome of the behind-the-wheel driving test by discriminant analysis or cut-off procedures based on neuropsychological and/or other subject-related data yielded a maximum of only 72% correct decisions. In view of the frequent impairment in driving ability after brain damage it is recommended that an on-road driving test is taken in each case. In case of failure, a subsequent and detailed psychometric assessment may support indications for rehabilitative measures to regain driving ability.

Introduction

When discussing the issue of driving ability after brain damage with psychologists or medical doctors, you will sometimes hear the opinion that people who have suffered brain damage should - for their own safety and that of others - under no circumstances be allowed to

*Department of Psychology, University of Bielefeld, Germany

resume driving. People support this opinion by arguing that even in patients who have recovered well, there might always be some hidden functional deficit which may, at some time, become dangerous.

Even if neurological or neuropsychological examinations have yielded no evidence of cognitive impairments, it is argued that there could still be a "personality change" coupled, perhaps, with a loss of insight into one's own capability. At a meeting on traffic psychology a colleague once remarked sarcastically, with reference to a "Django" western movie, that "dead bodies will mark the patient's path".

Indeed, permission to drive is no basic right and there is no reason whatsoever why patients should not use public transport. So why take the trouble of evaluating a patient's driving ability in the first place? In my opinion, there are several reasons:

- Society expects patients to return to work whenever possible even if there are still impairments left after brain damage. In many cases the risk is accepted that deficits in, for example, attention may lead to mistakes or even accidents at work. Only serious disorders such as epileptic seizures — but not, for example, a moderate or minor reduction in attentional capacity — are considered a reason to exclude patients from working on machines or driving motor vehicles or fork lift trucks etc. It seems only fair, therefore, to take the trouble of ascertaining whether a patient is or is not able to drive again.
- The use of public transport is, as we all know, not always adequate or satisfying, for example if one lives in the country, and using a taxi over greater distances is too costly in the long run. Often patients are also not able to carry heavier goods, and a car of their own therefore is a great help.
- Not all, but many of us enjoy driving and claim that it can be relaxing. No doubt many people, men in particular, also consider having a driving licence as important for their self-esteem. In any case, a positive decision on a patient's driving ability may contribute to the process of rehabilitation by making him or her more independent and supporting social activities. A study by Legh-Smith, Wade & Hewer (1986) found that the frequency of depressive symptoms was lower in brain-damaged patients who resumed driving compared to those who did not.

Thus, if we accept that it is worthwile to take the trouble to assess driving ability after brain damage, which is the best way to do this?

There have been a number of studies attempting to predict the driving ability of brain-damaged patients from their performance in various psychometric tests. According to the common opinion that attentional capacity, speed of visual orientation and speed of reaction are most important for safe driving, tests aiming at these functions were included in all studies, together with various other tasks measuring general intelligence, memory performance, spatial orientation, or sensorimotor coordination (Engum & Lambert, 1990; Galski et al, 1990, 1992, 1993; Katz et al, 1990; Nouri et al, 1987; Sivak et al, 1984; Sundet et al, 1995; Wilson & Smith, 1983).

Most of these studies suffer, however, from one or the other of the following problems:

- Often, rather small groups of patients were examined (Galski et al, 1992, 1993; Golper et al, 1980; Gouvier et al, 1989; Klavora et al, 1995; Quigley & DeLisa, 1983; Sivak et al, 1981, 1984; Wilson & Smith, 1983; van Zomeren et al, 1988) and either no or only a very limited practical driving task in a sheltered off-road area was included (Galski et al, 1992 ; Gouvier et al, 1989 ; Sivak et al, 1981, 1984 ; Wilson & Smith, 1983).

- When a more extended on-road driving test was used as an external criterion against which the predictive value of the psychometric test results was assessed, the patients were sometimes preselected with a bias to exclude the more seriously impaired subjects who were suspected on a priori reasons to fail the driving test or who were believed to be too risky for on-road driving (Jones et al, 1983 ; Katz et al, 1990 ; Sundet et al, 1995).
- In other studies too large a set of variables was used in multivariate discriminant functions, with the consequence that the resulting classification functions capitalize on random characteristics of the data set and that the reliability of the obtained high correct prediction rates must be doubted (Galski et al, 1990 ; Golper et al, 1980 ; Nouri et al, 1987 ; Sundet et al, 1995 ; Wilson & Smith, 1983).
- In some studies a high ratio of correct predictions was achieved, but only when accepting a rather large proportion of unclassified "borderline" cases (Engum & Lambert, 1990),

Due to these problems and in view of the fact that some studies observed only a moderate correlation between psychometric test results and the outcome of an on-road driving assessment, skepticism with regard to the validity of a purely psychometric approach still appears to be justified (Handler & Patterson, 1995 ; Hannen et al,, 1998 ; van Wolffelaar et al, 1 988 ; van Zomeren et al, 1987 ; Brouwer & Withaar, 1997).

My interest in the evaluation of brain-damaged patients' fitness to drive was triggered by Prof. Klaus Poeck in the early 80s, who asked me to assess the attentional capacity and speed of reaction in some of his patients in order that he could advise them whether to drive or not to drive. Some of these patients were not at all happy with my diagnosis and persisted that they were, indeed, able to drive and had been using their car again without any problems. So I decided not to rely on my tests only but to organize an on-road driving probe for the sake of the patients, and perhaps of others participating in traffic. We started with a driving test of 45 minutes, and extended this to 90 minutes, under the pressure of the argument that a possibly reduced tolerance to physical and psychological stress would not necessarily become evident within a shorter period of driving.

Method

Between 1990 and 1994 we examined 116 patients from two institutions, the Department of Neurology at the University of Aachen and the Neurological Rehabilitation Centre in Bonn. Only those subjects were included who had driving experience of at least three years or 50,000 kilometres. We excluded patients with deficits and disorders in the field of neurology, internal medicine or ophthalmology which precluded driving in any case like, for example, large hemianopic field defects, epileptic seizures, diabetes not sufficiently controlled by the patient, or massive cardiac insufficiency. However, patients were not excluded because of cognitive, perceptual or motor impairments, in fact we intentionally included patients with even significant functional impairments.

The characteristics of the sample are given in table 1. There is a preponderance of aphasic subjects. On the one hand this is due to the fact that the study was carried out mainly at the Neurological Department in Aachen which has a focus on aphasia. A second, and perhaps more important reason, was the fact that aphasic pa-

Table 1 Sample characteristics

	Subgroup	
	Aphasic (n = 67)	Nonaphasic (n = 49)
Age (Yrs)		
Mean	48.1	43.3
SD	12.0	12.3
Range	23-72	21-69
Duration (Mos)		
Mean	22.9	20.5
SD	32.9	22.1
Range	1-219	2-113
Etiology		
Vascular	63	31
Traumatic	2	17
Other	2	1
Localization		
Left	59	13
Right	3	13
Bilateral	5	23

tients in particular worry about the risk of running into severe problems, even being mistaken as being drunk, when getting into a routine traffic control or being involved in a minor traffic violation. Frequently, these patients spontaneously ask for an evaluation and confirmation of their driving ability.

The etiology in the aphasic subgroup is, of course, mainly vascular, with a left-sided localization, whereas in the non-aphasic subjects there is also a high proportion of traumatic head injury and bilateral localization. Not unexpectedly, the mean age of the aphasic group is somewhat higher than that of the other group.

All patients participated in a practical 1 $^1/_2$ hour on-road driving test supervised by an experienced licenced driving instructor. This included driving on motorways, country roads and in busy city traffic. For hemiplegic patients the car was technically adapted to meet the requirements of operating the pedals (brake and accelerator) and the steering wheel with only one foot and/or one hand.

During driving the patient's driving behav-

Table 2 Categories of driving behaviour

Directional signalling
Careful observation of traffic
Getting into lane adequately
Tracking in lane
Merging into flowing traffic
Adjusting of speed
Respecting speed limits
Keeping distance
Following sign posts
Paying attention to traffic lights
Stopping at danger points
Respecting oncoming traffic
Respecting bicycle tracks

iour was recorded as correct or incorrect by the instructor who used a protocol with more than 280 observational items for the whole route, such as careful observation of the traffic and taking precautions, directional signalling, keeping in lane or "tracking", changing lanes, stopping at traffic lights if necessary, observing speed limits, giving the right of way, etc. In the later evaluation of the protocol the items were alotted to 13 categories, as shown in table 2. For each category the percentage of adequate behaviours was calculated, serving as parameter for the later statistical analyses.

In addition, the driving performance was globally rated by the instructor according to German school marks ranging from 1 to 6, that is from excellent to very poor. Marks 1 to 4 indicate passing, 5 and 6 failing of the driving test. This rating was based on the instructor's comprehensive impression concerning the adequacy and safety of driving.

Technical aspects of driving, that is the skill of handling the car, were not taken into account as long as they did not interfere with driving safety.

The psychometric examination of the patients comprised 6 tests. Four of these correspond to the test procedures usually applied by a German company officially entrusted with the supervision of vehicle and driver safety (Technischer Ueberwachungsverein):

- In a first test 20 slides of real-life street scenarios are presented for 0.9 sec each. The subject has to mark on a multiple choice array which of the following categories were present: pedestrians, two-wheeled vehicles, motor cars, traffic signs, and traffic lights. The number of errors, that is misses and false-positives, is recorded. The maximum error score is 100.
- In a second test, presumed to measure rapid visual orientation, there are 10 slides each showing 9 entangled irregularly curved lines with letters as start markers and digits as end markers. The patient has to indicate the respective end marker for each line. Each slide is presented for 40 sec. The maximum number correct is 90.
- As a third task reaction time is recorded for simple auditory or visual signals as well as for a particular combination of two signals.
- In a more complex reaction task the patient has to respond as quickly as possible to a variety of visual and auditory signals by pressing keys with hand or foot. With hemiparetic patients stimuli for the paretic foot are replaced by stimuli for manual response. The number of both correct and incorrect responses during the 5-minute testing session is recorded.
- In addition, a cancellation task was given in which all letters "d" marked by two strokes had to be crossed out as quickly as possible. The performance is measured on the standard Z-scale.
- Finally, the general level of intelligence was measured with the performance part of the Wechsler Scale and with a psychometric intelligence profile (LPS) used in Germany.

Results

Figure 1 shows the frequency distribution of marks given by the driving instructor. The whole range of marks is represented, with the mean at mark 4. Fifty-eight percent of the patients failed, meaning obtained marks of 5 or 6.

It may be interesting to note that out of 28 patients who had decided for themselves to resume driving because they felt themselves to be fit to drive after recovering from the acute phase of illness, 36% actually failed our on-road driving test (compared to 62% of the patients who had not yet resumed driving).

In order to examine the effects of the presence of aphasia, paresis of upper and lower extremities and minor visual field defects we classified the patients according to these impairments. Because field defects proved highly significant, that is of the 13 patients in whom field defects were detected 11 failed the driving test, we restricted the further analysis to only those cases for whom the ophthalmological examination was negative. In these remaining cases paresis of the arm was significantly correlated with driving performance whereas there was only a trend that patients with paresis of lower extremities failed the driving test. Although 48% of the aphasics and only 35% of the non-aphasic patients failed, this difference was not significant. Comparing patients with left-sided, right-sided and bilateral lesions yielded no significant difference.

Our main interest, however, focused on the predictive value of the psychometric test results with regard to the outcome of the on-road driving test. For this purpose we used the method of stepwise discriminant analysis. The results are summarized in table 3. For the classification of the cases the so-called jackknife procedure was applied: this means the case to

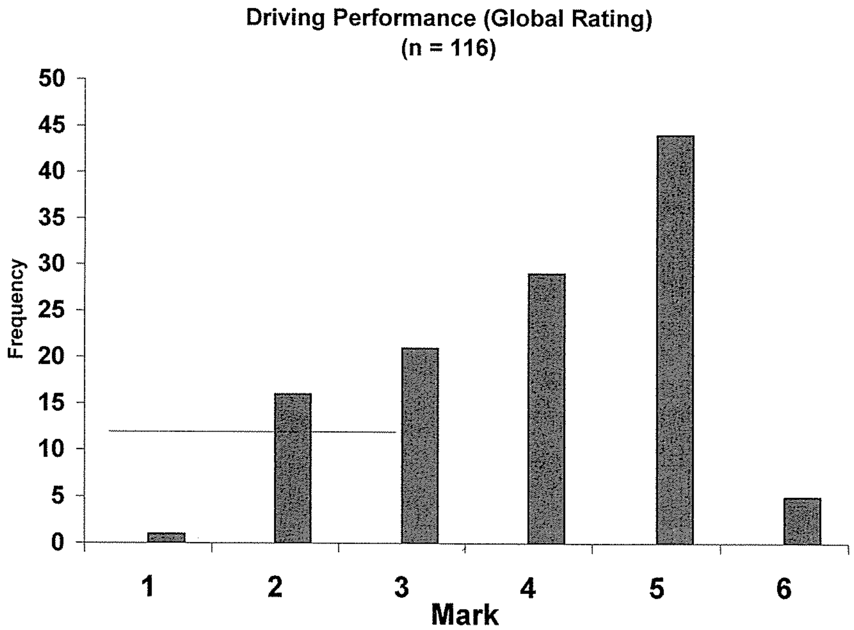

Figure 1 Distribution of marks 1 to 6 given by the driving instructor according to his global impression on the patients' driving behaviour during the on-road driving test.

be classified is excluded from the calculation of the discriminant function. This procedure comes close to the requirements of a cross validation of the discriminant function with independent subject samples.

When the 9 psychometric variables were used in the analysis, the procedure selected only one for the prediction, namely the number of correct reactions in the complex reaction task. Only 67% of the patients were correctly classified. Correct positive and correct negative decisions were roughly balanced.

When we tried to predict the outcome of the driving test from a set of subject-related data, namely age, duration of illness, presence of small field defects, amount of driving practice, and number of traffic accidents before the illness, the stepwise procedure selected the variables age and visual field defects as most predictive, leading to a proportion of 72% correct classifications, with a preponderance of correct positive predictions (i.e., passing the driving test).

As the next step we included both, psychometric and subject-related variables in the analysis. Two variables were selected for the discriminant function, that is number of correct reactions in the complex reaction task together with presence or absence of visual field defects. This discriminant function yielded a total of 73% correct classifications with no difference between correct positive and correct negative predictions.

When we followed the decisional procedure usually applied by the "Technische Ueberwachungsverein" in the individual evaluation of driving ability, the proportion of correct decisions amounted to 70%. This is a cut-off procedure which uses four psychometric variables from the tachistoscopic presentation of street scenarios, the overlapping lines task, and the complex reaction task, and which requires

Table 3 Prediction of outcome of the on-road driving test by discriminant analysis or cut-off classification based on psychometric test results, subject-related characteristics and driving behaviour

Variables Used for Prediction	Prediction (%) of Outcome of On-Road Driving Test			
	Correct Pos.	Correct Neg.	False Pos.	False Neg
Correct Reactions in Complex Reaction Task	36	31	9	24
Age & Visual Field Defect (VFD)	46	26	18	10
Correct Reactions & VFD	37	36	7	20
Cut-off Classification (4 Variables)	41	29	13	17
Tracking & Careful Observation of Traffic	51	29	14	6
Correct Reactions & VFD & Tracking	48	32	11	9

that a subject achieves a percentile score of at least 15 in three variables for a positive decision.

In order to examine the degree to which the driving instructor's subjective global judgement on driving ability could be "predicted" from the behaviour recorded in the detailed driving protocol, a stepwise discriminant analysis was carried out with the 9 most frequently observed categories of behaviour. Tracking and careful observation of traffic were selected, and with these the pass or fail judgement was predicted with an accuracy of 81% and a preponderance of correct positive decisions.

One may wonder why there is no perfect correlation between the recorded driving behaviour and the driving instructor's decision. This can be explained by the fact that the driving test was judged as failed if the instructor felt compelled to actively intervene, for example, by braking or assistive steering, in order to prevent an accident. This occurred also in patients eventually passing the test, but only in 14% of these cases as compared to 80% of the subjects failing the driving test.

Finally, a combination of the most predictive variables from psychometric test results, subject-related variables and driving behaviour categories was subjected to stepwise discriminant analysis. The variables correct reactions in the complex reaction task, visual field defect and tracking were included in the discriminant function which yielded a total of 80% correct decisions. However, this seemingly favourable result is more of theoretical than of practical value because once the on-road driving test has been performed, its outcome according to the instructor's judgement will, of course, be the best choice for the decision on a patient's fitness to drive.

In summary, our results indicate that psychometric and subject-related variables do, to some degree, contribute to the diagnosis of driving ability, with a hit rate of roughly 70%. This could be regarded an improvement compared to the base rate of approx. 60% of the patients passing and 40% failing the driving test. However, this gain is certainly not satisfactory in the case of individual decisions.

The problem is that it can be argued that the validity of the on-road driving test as the external criterion of driving ability is questionable. It is frequently objected that relatively rare, but critical situations may not occur during the 1 $^{1}/_{2}$ hour driving test like, for example, the notorious ball rolling into the road chased by a child or the unexpected dropping of a large object from a truck. It is suspected that even a moderately increased simple reaction time would be disastrous and that reaction time measurement, therefore, has a predictive value.

Because such critical events can, of course, not be provoked during an on-road driving test, it is often suggested that the driving ability should be tested in a driving simulator (Galski et al, 1997 ; Gianutsos, 1994). Up to now, there are only very few sophisticated simulators available, at least in Germany, and there are not yet any reliable norms available for comparing the behaviour of patients with that of healthy persons in rarely occurring, but particularly critical, circumstances.

It would not be surprising if quite a number of normal subjects failed in such simulated events but with nobody worrying about their driving licence. Further, it is well known that the majority of serious traffic accidents is caused by healthy, but still unexperienced, young drivers whose speed of reaction and also general psychophysical capability are not in doubt. Safe driving does not so much depend on a high speed of reaction, or other skills on the so-called operational level, but rather on the ability to avoid situations which require an ultimately fast reaction. This ability, taking place on a tactical and strategical level, can hardly be assessed by laboratory tests. It can be observed, however, during real-life driving. Summing up, at the moment an extensive practical driving test appears to be a good, if not the best, choice.

Further. I would like to draw your attention to the rule that a negative decision regarding future driving should only be made if there is good reason to expect an accident occurring in the near future and not the mere possibility — which can, of course, never be excluded — of an accident occurring in the distant future. This rule is stated in the guidelines (entitled "Diseases and Motor Traffic") which have been developed by a large board of medical experts and edited by the German Ministery of Traffic in order to help with the judgement of driving ability (Bundesministerium für Verkehr, 1996).

To cut a long story short and to draw a conclusion, I would strongly recommend that an extended on-road test should be given in each case of those brain-damaged patients who, from a medical point of view, could be considered to be fit to resume driving, and that the decision should be based primarily on the outcome of the driving test. It must be noted that this differs from the frequently given recommendation to select only those patients for the on-road driving who are "borderline cases" in terms of neuropsychological test results.

In this context one should remember the fact stated above, namely that even of the patients who made their own decision to resume driving, 36% failed the driving test. This observation clearly shows the necessity that an on-road driving test should be administered in each case.

This procedure is not, by the way, unduly expensive as is sometimes objected by colleagues favouring extensive neuropsychological testing and distrusting any straightforward practical approach.

The second issue of this paper concerns the rehabilitation of driving ability. Although some studies have included an attempt to restore driving ability in brain-damaged patients (Gianutsos, 1994 ; Jones et al, 1983 ; Kewman et al, 1985 ; Quigley & DeLisa, 1983 ; Sivak et al, 1981, 1984 ; Timm & Hökendorf, 1994) it still remains difficult to draw a reliable conclusion regarding the question which procedures should be followed and which rate of success can be expected (Brouwer & Withaar, 1997). Much of the uncertainty is due to the problems mentioned before, that is the use of small subject samples and a bias to preselect patients.

The training procedures that have been applied range from (1) paper-and-pencil or computer-assisted tasks relating to skills of visual scanning, attention, speed of reaction, visuospatial perception and orientation, planning and problem solving, to (2) simple non-interac-

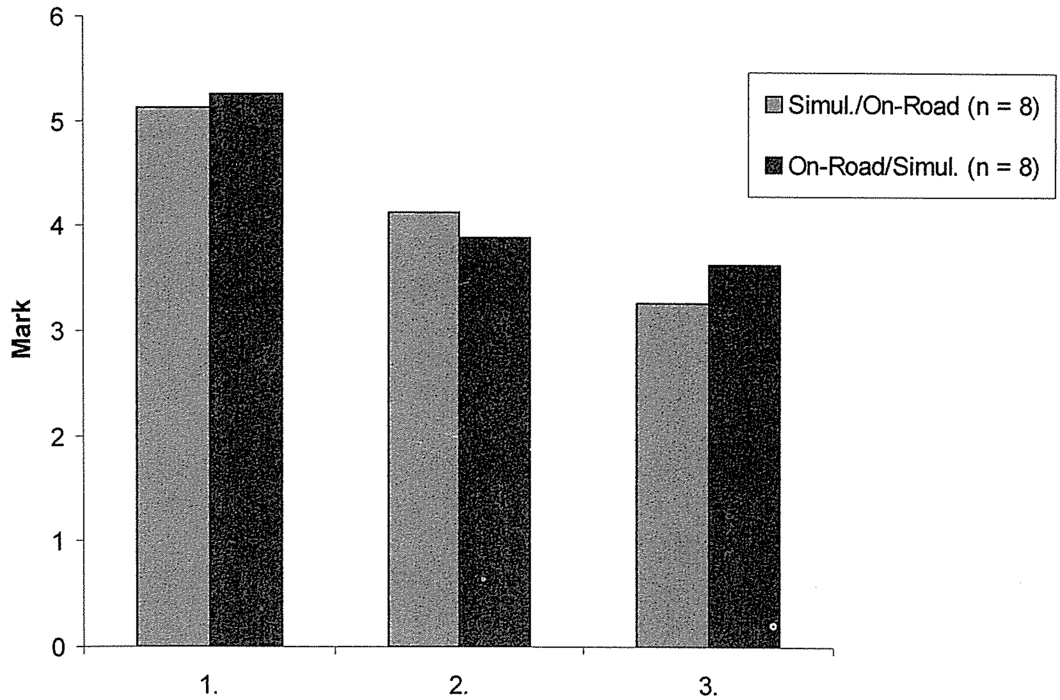

Figure 2 Effect of training by driving stimulator sessons and on-road driving lessons on the overall qualitiy of driving as judged by the driving instructor in three consecutive driving test ("Simul./On-Road" and "On-Road/Simul." denote the sequence of training procedures).

tive driving simulators with presentation of road-movies, the patient being required to adequately react by braking, accelerating or steering, to (3) training sessions in sheltered off-road areas, using either special small-scale vehicles or regular cars and exercising various manoeuvres like slalom, stopping in front of obstacles, parking in small spaces, etc., to (4) real-life on-road training sessions with the assistance of a driving instructor.

The common experience is that training procedures, and particularly those applying simulator sessions or behind-the-wheel driving lessons, can help to regain the fitness to drive. Up to now, however, no detailed description of promising procedures is available and it is, for example, an open question whether computer-assisted training in the neuropsychological laboratory or simulator-training have any advantage at all over the usual on-road driving lessons supervised by an experienced driving instructor.

It is generally felt that training on the level of tactical and strategical behaviour may be more important than training on the level of operational skills. Therefore, a technically sophisticated and interactive driving simulator would be most promising for training. Such apparatuses are, however, extremely expensive and, at present, only a few are available. In contrast, it is very easy to organize on-road driving lessons practically everywhere in the neighborhood of the patients.

A study comparing the effect of simulator training with that of on-road driving lessons is currently in progress at a neurological rehabilitation centre (Johanniter-Ordenshaeuser Bad Oeynhausen) cooperating with the University of Bielefeld. Patients admitted to the study are first given a standard on-road driving test.

Those failing this test participate in the training. A cross-over design is used in which half of the patients start with 10 sessions of simulator training, with approx. 30 min per session ; after a second on-road driving test they continue with 5 on-road driving lessons, each of 45 minutes duration ; thereafter, a third and final on-road test is given. The training sequence is reversed for the other half of the patients.

Unfortunately, the study proceeds slowly so that only preliminary results can be reported. The effect of the training is shown in figure 2. In the subgroup starting with simulator training 62% of the patients passed the second on-road test and all patients succeeded in the third on-road test following the real-life driving lessons. Of the patients starting with driving lessons 62% passed the second on-road test and 75% succeeded in the third on-road test following the phase of simulator training. A statistical comparison did not reveal any significant difference in efficacy between the two training procedures. However, because of the still very small sample this result must be regarded with precaution,

Considering the effect of the combined training, 87% of the patients reached the criterion of sufficiently safe on-road driving. And from this point of view it does not matter whether or not the first two on-road driving tests may also have contributed to this effect.

A technically much more refined driving simulator has been developed with financial support from the Kuratorium ZNS and has just been set up at the Neurological Rehabilitation Centre in Bonn. In this simulator the subject is presented with a very complex and realistic traffic scenario seen "through" the windscreen of the subject's own car. The simulated traffic in which the patient participates by almost freely moving his car is highly variable, with the possibility to pre-program many important parameters, in addition to the random occurrance of other traffic events. The simulator will be used in the future for the training and testing of a large number of neurological patients, and the efficacy of the simulator as a testing and as a training device will be validated against the results of on-road driving tests. In addition, a group of healthy subjects will be submitted to the procedure in order to establish normative data .

It can be expected that within the next two years important insights will be obtained from this study at the Bonn-Bad Godesberg Rehabilitation Centre.

Acknowledgement : I wish to thank Mrs A. Waddington for language assistance.

References

1) Brouwer WH, Withaar FK : Fitness to drive after traumatic brain injury. Neuropsychol Rehab 7 ; 177-193, 1997

2) Bundesministerium für Verkehr (Hrsg) : Krankheit und Kraftverkehr. Begutachtungs-Leitlinien des Gemeinsamen Beirats für Verkehrsmedizin. Köllen Druck+Verlag, Bonn, 1996

3) Engum ES, Lambert EW : Restandardization of the cognitive behavioral driver's inventory. Cogn Rehabil 8 ; 20-27, 1990

4) Galski T, Bruno RL, Ehle HT : Driving after cerebral damage : A model with implications for evaluation. Am J Occ Ther 46 ; 324-332, 1992

5) Galski T, Bruno RL, Ehle HT : Prediction of behind-the-wheel driving performance in patients with cerebral brain damage : A discriminant function analysis. Am J Occ Ther 47 ; 391-396, 1993

6) Galski T, Ehle HT, Bruno RL : An assessment of measures to predict the outcome of driving evaluations in patients with cerebral damage. Am J Occ Ther 44 ; 709-713, 1990

7) Galski T, Ehle HT, Williams JB : Off-road driving evaluations for persons with cerebral in-

jury : a factor analytic study of predriver and simulator testing. Am J Occ Ther 51 ; 352-359, 1997
8) Gianutsos R : Driving advisement with the Elemental Driving Simulator (EDS) : when less suffices. Beh.Res.Methods 26 ; 183-186, 1994
9) Golper LAC, Rau MT, Marshall RC : Aphasic adults and their decisions on driving : An evaluation. Arch Phys Med Rehabil 61 ; 34-40, 1980
10) Gouvier WO, Maxfield MW, Schweitzer JR et al : Psychometric prediction of driving performance among the disabled. Arch Phys Med Rehabil 70 ; 745-750, 1989
11) Handler BS, Patterson JB : Driving after brain injury. J Rehabil 61 ; 43-49, 1995
12) Hannen P, Hartje W, Skreczek W : Beurteilung der Fahreignung nach Himschädigung. Neuropsychologische Diagnostik und Fahrprobe. Nervenarzt 69, 1998 (inpress)
13) Jones RD, Giddens H, Croft D : Assessment and training of brain-damaged drivers. Am J Occ Ther 37 ; 754-760, 1983
14) Katz RT, Golden RS, Butter J et al : Driving safety after brain damage : Follow-up of twenty-two patients with matched controls. Arch Phys Med Rehabil 71 ; 133-137, 1990
15) Kewman DG, Seigerman C, Kinter H et al : Simulation training of psychomotor skills : teaching the brain-injured to drive, Rehab Psychol 30 ; 11-27, 1985
16) Klavora P, Gaskovski P, Martin K et al : The effects of dynavision rehabilitation on behind-the-wheel driving ability and selected psychomotor abilities of persons after stroke. Am J Occ Ther 49 ; 534-542, 1995
17) Legh-Smith J, Wade DT, Langton-Hewer R : Driving after stroke. J Royal Soc Med 79 ; 200-203, 1986
18) Lings S, Jensen PB : Driving after stroke : A controlled laboratory investigation, Int Disabil Stud 13 ; 74-82, 1991
19) Nouri FM, Tinson DJ, Lincoln NB : Cognitive ability and driving after stroke. Int Disabil Stud 9 ; 105-115, 1987
20) Quigley RL, DeLisa JA : Assessing the driving potential of cerebral vascular accident patients. Am J Occ Ther 37 ; 474-478, 1983
21) Sivak M, Kewman DG, Henson DL : Driving and perceptual/cognitive skills : Behavioral consequences of brain damage. Arch Phys Med Rehabil 62 ; 476-483, 1981
22) Sivak M, Hill CS, Henson DL et al : Improved driving performance following perceptual training in persons with brain damage. Arch Phys Med Rehabil 65 ; 163-167, 1984
23) Sundet K, Goffeng L, Hofft E : To drive or not to drive : Neuropsychological assessment for driver's license among stroke patients. Scand J Psychol 36 ; 47-58, 1995
24) Timm H, Hökendorf H : Möglichkeiten von Diagnostik und Training der Fahrtauglichkeit mittels stationärem Übungs-Pkw. Rehabilitation 33 ; 237-241, 1994
25) Wilson T, Smith T : Driving after stroke. Int Rehabil Med 5 ; 170-177, 1983
26) Woldert M, Ritter G : Hirntumorkranke im Straßenverkehr. Klinische und verkehrsmedizinische Untersuchungen zur Straßenverkehrsdelinquenz. Nervenarzt 54 ; 304-310, 1983
27) Wolffelaar P van, Zomeren E van, Brouwer W et al : Assessment of fitness to drive of brain damaged persons. In Road user behaviour — theory and research. ed by Rothengatter JA, DeBruin R, Van Corcum, Assen, pp.302-309, 1988
28) Zomeren AH van, Brouwer WH, Minderhoud JM : Acquired brain damage and driving : A review. Arch Phys Med Rehabil 68 ; 697-705, 1987
29) Zomeren AH van, Brouwer WH, Rothengatter JA et al : Fitness to drive a car after recovery from severe head injury. Arch Phys Med Rehabil 69 ; 90-96, 1988

(Japanese Journal of Neuropsychology 15 ; 9-19, 1999)