The Driving Advisement System:
A Computer-Augmented Quasi-Simulation of the
Cognitive Prerequisites for Resumption of
Driving after Brain Injury

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No other activity so starkly pits the needs of the
individual recovering from brain injury against the
protection of society than does operating a motor ve-
cicle. Cognitive abilities (e.g., response to complex
processing demands, impulse control, ability to sustain
performance, mental flexibility, and judgment), while
evident only indirectly, are essential to performance,
yet few are well sampled in currently used assessment
procedures, which, instead, emphasize visuo-motor co-
ordination and reaction time. In response to this need,
a computerized quasi-simulation, the Driving Advis-
ement System (DAS), was developed and is introduced
here. The DAS incorporates a set of computer-based
tasks for use by professionals charged with rendering
advice concerning cognitive abilities necessary for
driving safely. Normative data on DAS measures were
obtained from a group of over 60 safe drivers free of
significant neurological impairment. Preliminary val-
idaion findings are summarized. A sample DAS-gen-
erated report for a brain-injury survivor, who sought
to resume driving, is used to illustrate the graphic norm-
referred presentation of an individual's perform-
ance together with self-appraisal ratings.

Key Words: Driving—Cognition—Assessment—
Brain injury.

More than any other activity that the survivor of
a brain injury could engage in, driving pits the needs
of the individual against the protection of society.
In order to make rational decisions about whether
to resume driving (or to continue driving in the case
of persons with deteriorating conditions), drivers
and other concerned persons need evaluation, feed-
back, and advice. The purpose of predriving as-
essment of cognitive abilities is to address these
needs with minimal risk. Off-the-road procedures
can serve a useful screening function and identify
individuals who are indeed ready for on-the-road
training and testing. Unfortunately, on-the-road
assessment by specialists in brain-injury rehabili-
tation is not universally available, is costly, incurs
some risk, and is itself not standardized. When on-
road assessment is available, off-road assessment
still offers complementary information, for exam-
ple, quantification of mental processing efficiency,
and the objectivity of standardized measurement
protocols with established reliability and validity.

Preditving advisement may lead to recommenda-
tions that the would-be driver make alternative
plans for mobility. Often it contributes to planning
for driver rehabilitation (retraining, compensation,
and adaptive devices). Sometimes this process serves
to encourage overcautious drivers who need reas-
surance (1).

Driving is an issue that should be addressed by
all brain-injury rehabilitation programs (especially
transitional living and community reentry), which
strive to enable people to reenter a society, such as
ours, where most adults achieve mobility through
driving.

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Prevailing Methods of Predriving Assessment

Before reviewing the best current approaches, we need to consider what usually happens. Many programs take a passive approach and address the issue of driving only in those cases where the matter is brought to their attention by individuals or family members.

Physician’s Examination and Report

Typically, departments of motor vehicles rely on physician’s recommendations. While they might consider the opinion of a neuropsychologist or occupational therapist, they usually require a physician’s report. The physician is thus placed in the difficult position of rendering an opinion both about complex cognitive functions, which they are rarely prepared to evaluate, as well as driving, a domain of performance in which they have had no training or experience other than as drivers themselves.

Porto Clinic Glare and Supplements

In rehabilitation facilities, predriving assessment programs are typically conducted through the departments of occupational therapy (2,3). Many of these use a device called the Porto Clinic Glare (4). In approximately 20 minutes this device screens a variety of visual functions including visual acuity, visual fields, depth, glare recovery, color vision, and reaction time (three trials for simple reaction time and three more for choice reaction time). Guidelines for concluding that performance is adequate are offered on the examiner’s score sheet. Many therapists report, however, that these are too strict—unaware that these criteria are based on the performance of marine recruits. Alternatively, many facilities use the AAA Automatic Brake Reaction Timer (5), which allows more trials. Supplemental assessments of visual perception are often used, e.g., the Motor Free Visual Perception Test (6), although their relationship to driving is, at best, uncertain (7).

In-Vehicle Road Test

Individuals who perform in a satisfactory way on the above procedures may then be offered an on-the-road assessment.

By and large, on-road evaluations are conducted by occupational therapists or driving instructors interested in rehabilitation. Many therapists use a set of routes of graded difficulty, through which they advance only as they judge the individual capable. They are guided by a checklist, which they developed based on experience. This form includes driving situations and behaviors, e.g., stopping appropriately at intersections, speed control. Certain behaviors result in automatic disqualification, e.g., failing to observe STOP signs. Rarely are these checklists quantified and many therapists acknowledge a substantial subjective component or “sweat standard.”

Not infrequently, an individual will be failed for more global reasons such as poor judgment, unrealistic self-appraisal (overconfidence), failure to appreciate the significance of potential hazards or risks, or deterioration of performance under situations of increased complexity and demand. After being failed for these reasons, the individual and families often do not appreciate the basis for the failure. Further, they lack a clear indication of what they might do to rectify the situation.

Essential as they are for comprehensive driving rehabilitation, in-vehicle assessment protocols are plagued by lack of standardization and empirical validation against safety and amount of driving. One cannot assume that on-road driving tests are themselves valid. Like any assessment they must be standardized and shown to be reliable and valid.

Recent Advances

A number of new procedures promises to advance the state of the art.

Preview Tracking

Among these are dynamic computerized pursuit-tracking procedures. A study from New Zealand (8) used a “preview-tracking” task and demonstrated that head-injured individuals are less able than non-brain-injured controls to utilize foreknowledge of the roadway ahead (preview).

Neuropsychologically Rationalized Test Battery

Several reports have suggested that conventional neuropsychological tests can have validity for predicting driving performance (9–13), whereas others (14) have not confirmed this result. For use with brain-injury survivors, it would be hard to dispute the potential value of a neuropsychologically meaningful set of tests, especially if it were guided by a task analysis of driving. The failure of Galski et al. (14) to find consistent relationships between neuropsychological test performance and assessments of driving may reflect test selection, small samples, and methodological artifacts (e.g., converting scores into pass and fail outcomes, which throws away detailed information and relies instead on cut-off values).
The biggest disadvantage of conventional neuropsychological procedures is that they lack apparent validity as driving tests to the would-be driver. A person who does poorly connecting letters and numbers in an alternating series, as on the Trailmaking Test, is unlikely to be convinced that the failure has any implications for driving safety.

**Driver Performance Test (DPT)**

The DPT (15,16) is a videotaped procedure in which a series of situations is presented to the individual with several optional responses. These alternative responses are scored from “ideal” (5-point) to “less ideal but still adequate” (3-point) responses and then to others that are not desirable. Scales are alleged to reflect five different aspects of driving: search, identify, predict, decide, execute. Standardization information is available for ordinary drivers as well as those who drive professionally (truck drivers).

The DPT is readily implemented, and an individual can complete it independently in less than an hour. Scoring for the DPT is simplified by a computer program that computes overall and scale scores, as well as frequencies with which each option was selected (17).

It would be difficult if not impossible for an aphasic to do the DPT. Because clinical experience and some data (18) show that aphasia does not necessarily preclude safe driving, the verbal demands of the DPT limit its usefulness for some returning drivers.

A caution regarding the DPT is that it is possible to obtain respectable scores by consistently choosing the same letter (B is best choice throughout). It would be prudent to check response sheets for response bias.

At a minimum, the DPT offers a challenging visual perceptual assessment. Gouvier et al. (9) found that it correlated best with driving in able-bodied control subjects, differentiating at the upper end of the scale. Relative to other measures, it is difficult: it requires that the individual respond quickly and move on to the next situation as paced by the videotape, and it requires discriminations between ideal and adequate responses, not just between extremes of “safe” and “unsafe” responses. The DPT is practical and has clinical value because of its apparent validity to would-be drivers.

**Computerized Assessments of Visual Search and Reaction Time**

In independent studies two of the author’s own computerized perceptual tasks, REACT (19) and SEARCH (20), have been demonstrated to correlate with driving-related measures (7,21). Feedback on the usefulness of these procedures encouraged the author to develop the present set of computerized tests explicitly designed for predriving advisement. A report by Sundet et al. (13) described a predriving assessment including REACT and a complex visual processing task, which also correlated highly with overall judged driving potential. The dynamic (real-time) properties of computerized tasks would seem important to their validity for driving.

**Simulators**

Studies of driving simulators, such as Blauw (22) show that they can be more valid than on-the-road testing (e.g., as a discriminator of driving experience). To be realistic a simulator ought to be interactive, in that the driver’s performance should affect the way the system looks and sounds, and ideally the way it feels. Designed mostly for driver education and training, the most widely used simulator (23) is not interactive and lacks assessment protocols with demonstrated reliability and validity. Further, the costliness of these devices limits their availability and therefore potential usefulness.

**Small-Scale Vehicle**

The Center for the Handicapped in Ruston, LA, at Louisiana State University has developed a small-scale vehicle, i.e., an adapted golf cart (9,24). This approach combines some advantages of an in-vehicle assessment without the attendant risks. The low speed of such vehicles limits their ability to simulate the information-processing demands of actual driving. However, individuals who have problems operating small-scale vehicles may benefit from experience with them. As with most simulators, cost is a significant factor.

**Standardized On-the-Road Assessment**

The most extensive attempt to develop a standardized on-the-road assessment is the Michigan driver performance test (25,26), which has been implemented on a national scale in New Zealand (27; D. Harwood, personal communication). In New Zealand it is used as part of the licensing process for learner drivers. Approximately 90% pass the test, which may, indeed, be appropriate for the general population of learner drivers (where there is a presumption of normalcy). The test serves more to define a standard of competency and influence driv-
er training, than to identify at-risk drivers. However, for drivers recovering from brain injury there can be no presumption of normalcy, and the need for diagnostic power is greater. If the New Zealand experience can be used as a guide, one must appreciate the investment needed to implement the Michigan test (e.g., extensive local studies and documentation of routes and 2 weeks of training for each examiner). The magnitude of this investment probably accounts for the observation that the Michigan test is not widely used in rehabilitation settings.

A more practical approach, geared for rehabilitation use, is embodied in the Occupational Therapy Driver Assessment Course sponsored by the Driver Education Centre of Australia. Therapists are advised to collaborate with local driving instructors to develop a series of routes of progressively increasing difficulty, and to function as an observer during on-road assessments. This evaluation approach, like the Michigan, is based on extensive training. While it has much promise, it needs psychometric development and dissemination to other countries.

Finally, there is another published protocol, The Safe Performance on Road Test (SPORT) (15), which is being used in at least one rehabilitation facility known to this author. Costs for vehicles, insurance, adaptive equipment, and training of examiners also discourages implementation of on-road assessment services. Nevertheless, a high priority must be placed on the development of a practical, empirically valid, on-road assessment protocol that can be implemented in a variety of geographic settings.

State of the Art

In three comprehensive reviews (28-30) persuasive arguments are presented for a shift of attention from the “operational” (mechanical skill) level to the complex cognitive factors, which dominate performance at the “tactical” and “strategic” levels. To reinforce their position, these reviewers point out that the group of drivers who are most accident prone (young males) is likely to perform best on measures of operational skill. At the tactical and strategic levels, the areas of judgment, insight, and planning are most important. It is just these areas that are most problematic for the returning brain-injured driver. Unfortunately, they are least well represented in predriving assessment protocols.

The most significant problem with current approaches is that there are areas in the cognitive domain that are addressed inadequately or not at all, for example: simultaneous processing, inhibition, adjusting to changing circumstances, judgment, and endurance. In the data that we do have available, e.g., Nouri et al. (31), Gouvier et al. (9), Schweitzer et al. (7) and van Zomeren et al. (29), the higher-order, more “cognitive,” factors seem to be most significant in differentiating brain-injury survivors from others. A very sophisticated study (32) of the effects of alcohol intoxication on simulated and closed-course driving showed the greatest effect of this central nervous system depressant on consistency of performance, ability to do more than one thing at a time, and ability to sustain performance over several hours. These findings reinforce us for placing a priority on incorporating and measuring the effects of task complexity and judgment, in concurrence with van Zomeren et al. (29) who urged that assessment should “emphasize the higher cognitive, . . . tactical and strategic levels.”

DRIVING ADVISEMENT SYSTEM: ADDRESSING THESE SHORTCOMINGS

The Driving Advisement System (DAS) was developed by the authors to guide assessment of cognitive prerequisites for driving and consequent counseling of would-be drivers after a brain injury. The core is an integrated set of computer-implemented procedures that were designed to have facevalue, as well as experimentally tested, validity. An explicit attempt was made to include the under-represented domains of ability discussed earlier. The remainder of this paper introduces the DAS, including its rationale, procedures, and initial clinical findings. Psychometric analyses have been presented at conferences (33-35). Formal reports are in preparation and further research is ongoing.

Consistency

Throughout, the DAS software affords the ability to study the consistency or inconsistency of performance. For instance, in the reaction time procedures, the individual is exposed to a minimum of 120 trials with up to another 120 in practice. Performance is displayed graphically on a trial-by-trial basis, which affords an immediate demonstration of variability, including lapses (“spikes” of reaction time). Also reported are summary indices of variability of reaction time (standard deviation).

“Real” Time

The DAS programs present tasks in “real” time, permitting more sensitive quantitative indicators of the ability to process information rapidly. Equally important, this dynamic property of the tasks
enhances their apparent validity because driving, after all, is a task in which time is very important. As will be discussed further, apparent validity is particularly important in the clinical acceptance of the information obtained.

**Cognitive Demand**

The DAS procedures explicitly address the complexity of information processing required of the individual. Response times are broken down into a decision component and an execution component, following the lead of van Zomeren (36) who has demonstrated the utility of this distinction in assessing head-injury survivors. As the DAS task demands increase in complexity, the choice component of the reaction time usually increases, but not the execution component. Clinically, a significant issue is whether the choice reaction time increases faster than it did for the standardization group. Approaches to remediation and interpretation would vary depending on whether the deficit was in the execution component (which might reflect a drug effect, a paresis, or other motor deficit) as opposed to the choice component, which emphasizes the mental (speed of information processing) aspect.

**Simultaneity**

The procedures require the individual to monitor more than one location on the screen and respond differentially.

**Inhibition and Modulation**

Inhibition and the ability to adjust to change are captured by a “reversing” choice reaction time task in which the response rules are reversed unpredictably back and forth throughout the assessment.

**Face (Apparent) Validity**

Clinical experience with predriving advisement underscores the value of using procedures that the examinee views as relevant. This attribute (apparent validity) is obviously important when one views the endeavor in the context of advisement, rather than assessment per se. Measures must be perceived as relevant in order to convince people to make what may be significant changes in their life style.

**Practice**

The DAS procedures afford ample opportunity for practice. Because driving is a highly practiced behavior, we encourage people to continue in practice mode until they feel they have reached their best level of performance. The emphasis is on the level of proficiency ultimately achieved, regardless of how long is needed to achieve it. This approach contributes to the clinical acceptance of these procedures, as people feel that they have been given the fairest possible chance.

**Judgment**

Finally, in the DAS the issue of judgment has been addressed in the following way: Before the performance measures are obtained, examinees are asked to predict their performance in relation to that of other safe drivers. They are given a scale with anchor points representing the average safe driver and the worst safe driver and are to adjust a marker along this continuum to reflect their predictions on several aspects of driving, such as, the movement component of reaction time, the decision component, field of view, consistency, and ability to adjust to different vehicles and circumstances. People who drive a great deal, including professional drivers, rarely overestimate their abilities, whereas some brain-injury survivors do so markedly.

The importance of self-appraisal is demonstrated by the per annum (not per mile) safety record of elderly drivers as a group (37,38). Their safety is predicated on their driving less and restricting the types of circumstances in which they drive. These adjustments are associated with a realistic self-appraisal of diminished capacities. A characteristic account might be “I know that I'm a lot slower than I used to be and therefore I not only drive slower, I do things to anticipate situations more and prevent problems from arising. Further I avoid driving in high-traffic situations at busy times of the day.” If survivors of brain injury could be induced to take a similar approach, it appears that their potential for being safe would be much greater. Data on a sample of elderly drivers in New Mexico suggest that these tendencies (awareness of limitations and restriction of driving) may be decreasing (39).

**DRIVING ADVISEMENT PROTOCOL**

**Preliminaries**

Before launching into formal assessment, DAS administrators explain the advisory purpose of the procedures. An understanding is reached on the obligations of the evaluator and the examinee, as well as to the disposition of any reports that will come from the evaluation. (Upon request, the first author
FIG. 1. The DAS hardware system. On the left is the “Portable” model and on the right is the “Standard.” On the standard model the protrusion and angle of the steering wheel may be adjusted. The foot-pedal assembly may be placed on the lap for hand operation. The pedals control momentary contact switches and are operated with only one foot (or hand).

will share a “Memo of Understanding,” which she has developed for this purpose.)

The DAS protocol includes laying a foundation for counseling. Bear in mind that an important purpose of the assessment is to offer information that will help the individual make the decision as to whether to proceed with applying for permission to drive again, to pursue further rehabilitation appropriate to this objective, or to achieve mobility in some other way.

The DAS (40) includes hardware (steering wheel, pedals, and interface) and computer programs. The DAS programs will run on any Apple II computer or compatible, or, IBM-compatible with a game port and a CGA (or more advanced) video board.

Hardware

The DAS hardware is illustrated in Figure 1.

Pedals

A three-pedal floor plate is laid out as follows: a middle (gas) switch equidistant from two identical switches, the left one of which is designated the brake and the right the horn. Each activates a normally open momentary-contact switch leading to a mini-phone plug. Other pedals or switches could be substituted to adapt to individual needs; however, they would require testing for equivalence of results. To permit separation of choice and execution components of response time, it is necessary to place the horn switch the same distance as the brake from the gas. This compromise with realism can be justified in part by the observation that drivers are often expected to adjust to different types of vehicles and arrangements of controls.

Steering Wheel

“Portable” and “Standard” wheels are available. Both rotate approximately 270 degrees lock-to-lock and sense rotation by a means of 150 K potentiometer with leads that plug into the interface. The Portable model is an 8-inch-diameter wheel, which is mounted in front of the keyboard as shown in the left panel of Figure 1. The Standard model is
a more realistic 10.5-inch wheel in a free-standing console, shown in the right panel of Figure 1. Adjustment of steering effort is possible in both models, although the amount of force is not quantified. Adjustment is friction based and is subjectively uniform throughout the travel of the wheel. A certain amount of force (effort) is usually necessary for best control. Modification can allow some degree of compensation for neurological impairment: increased tension may reduce the impact of tremors, whereas decreased tension may be necessary when weakness is a problem. Examiners are expected to adjust the tension on the wheel to enable the individual to perform as well as possible. If significant adjustment is needed, a rehabilitation engineer is consulted.

Interface

The pedals and wheel are connected to the computer through an interface to the joystick (game) port. The two switch inputs are used for pedal inputs, and one of the two joystick analog inputs is read by the software as a binary (pedal) switch; the other is used for the steering wheel.

Software and Protocol

The procedures are administered by an examiner using the computer. A full assessment protocol is intended to be conducted at one sitting. Although the procedures can be completed in less than an hour, allocating an hour and a half is recommended to allow ample time for discussion of the tasks and their relevance to driving.

SELF-APPRaisal

Although there is no particular reason to use the computer for this part of the assessment, it is convenient and assures that the responses are recorded in a fashion that will afford accurate and automatic analysis and reporting.

In SELF-APPRaisal, individuals use the steering wheel to move a marker that represents themselves in comparison to “other safe drivers.” They are presented with the display in Figure 2 and are told that the marker “AVE” is the average safe driver, and the marker “WORST” is the worst (but still safe) driver. Placing one’s mark to the left of WORST suggests a concern for one’s safety; placing it between WORST and AVE indicates that one feels below average, but still safe, whereas placing it to the right of AVE indicates an above average rating.

These self-ratings are obtained for eight different parameters likely to be important for driving: reaction time, decision speed, movement speed, speed of adaptation, consistency, concentration, field of vision, and impulse control. These parameters are explained carefully, and the examiner verifies that the individual understands the meaning of the ratings. An emphasis is placed on having the rating reflect one’s present status.

Self-ratings are also obtained for five questions: 1) Do you think you are capable of driving now? 2) How does your family feel about your driving? 3) Will your disability affect your ability to drive? 4) Do you fear losing control behind the wheel? 5) Do you expect to have difficulty (re)learning how to drive? A similar display is used for these ratings.

ON THE ROAD—Pursuit Tracking (with Preview)

The ON THE ROAD task consists of a display, illustrated in Figure 3, containing an abstract representation of a road with a small oblong block representing the vehicle. The vehicle can be moved from side to side. It does not go forward (up) or backward (down); instead the road itself changes, creating an illusion of movement.

The individual is told to hold down the gas pedal to keep the vehicle moving along the road and to use the steering wheel to maintain the vehicle in the center of the road. Unlike an actual gas pedal, this one is an all-or-none on-off type. The standard width road is 9 units wide (where a “unit” is defined as 1/6 of the screen width). The standard course is 516 units long, and the rate of advancement can be selected in advance by the user. With standard parameters it takes approximately 25 seconds to run through the course. The computer not only monitors the position of the vehicle constantly, it also gives a soft click whenever the vehicle touches the edges of the road, an event characterized as a “scrape.” If the vehicle goes off the road, a louder sound is made and a run is interrupted, an event characterized as a “crash.” Computer prompts are given to release the gas pedal and to bring the vehicle back to the center of the road, before resuming.

Modifiable parameters of ON THE ROAD include: 1) the speed of progress through the course, 2) the width of the roadway, 3) its difficulty or curviness, 4) the length of the course, and most significant in view of the Jones et al. (8) data, 5) the amount of preview of the roadway above the vehicle, i.e., the vehicle low on the screen affords the greatest preview, while high affords the least.
FIG. 2. SELF-APPRAISAL rating of self compared to others. This individual's marker is placed somewhat below average, but not as slow as the worst safe driver.

These parameters are preset in the full assessment protocol.

The full assessment protocol calls for at least four runs through the course, based on pilot studies, which showed that most standardization subjects leveled off by the fourth run. Following the principle that ample practice should be allowed, examinees may go through this course as many additional times as desired.

**BRAKE!—Simple Reaction Time**

The remaining three DAS procedures involve reaction time and do not require the steering wheel.

Figure 4 depicts the sequence of events in BRAKE!, starting with holding the gas pedl down to signify readiness. Whenever the letter "B" appears in either the left or right signal box, one releases the gas pedl and moves to the brake as quickly as possible. Then one results promptly from the brake to the gas to resume driving, as that “resumption” time will also be measured. Response times are measured in 100ths of a second, distinguishing “choice” (signal-on to release-of-gas) and “execution” (release-of-gas to press-of-brake) times.

Up to 40 practice trials are allowed. No data are saved while in practice mode. During this practice, the examiner encourages the individual to move quickly, even modeling or demonstrating the rapidity that is desired. All adjustments of position, pedal placement, etc. are completed during practice trials. When satisfied that the individual is performing as quickly as possible, the examiner can offer the opportunity to exit from practice mode before the 40-trial limit.

“False alarms” are recorded on trials where the gas pedl is released before the “B” signal appears. Obviously some individuals, in an attempt to reduce their response times, make errors of this sort. During practice trials, the examiner must discourage false alarms. If more than two or three occur in the 40 test trials, the reaction times themselves
become uninterpretable. False alarms suggest impulsivity and cast doubt on the ability to modulate performance in a driving situation where one must slow down in order to maintain the quality of performance.

Poor pedal control (e.g., foot slipping off the pedal, especially on return) will also result in “false alarm” errors. During practice the examiner must observe and attempt to correct this by adjustment of pedal placement, feedback regarding foot position, and, if appropriate, suggesting removal of thick-soled footwear.

**DECIDE—Choice Reaction Time**

The DECIDE task is identical to BRAKE! except that now the stimuli include an equal number of “H” (horn) trials in unpredictable sequence. When the “H” appears, whether on the left or right, the horn (right) pedal is to be pressed and not the brake (left) pedal. The instructions emphasize keeping erroneous presses to a minimum, even if it is necessary to respond more slowly, e.g., “Take your time. It’s worse to be wrong than to be slow.” Auditory feedback is used to draw attention to and discourage errors. The object is to be as quick as possible without making errors. Once again up to 40 practice trials are offered.

Some people are observed to release the gas the moment any signal appears and pause or vacillate before moving to the brake or horn. Choice then is deferred into the execution reaction time phase, which introduces ambiguity into the breakdown of choice and execution components in the scoring. Therefore, during practice, the examiner should discourage this pattern.

**INHIBIT—Reversing Choice Reaction Time**

In INHIBIT, the procedures again build upon those used in DECIDE. However, on a random half of the trials a sign appears in the center of the screen, which says “pedals reversed.” When this sign appears, the rules are reversed: that is, when the “B” appears, press the horn (right pedal), and when the “H” appears, press the brake (left pedal). The computer will switch unpredictably between “ordinary” mode and “pedals reversed” mode and demands rapid adjustment. Once again auditory feedback is used to discourage errors. The examiner cautions that this task can be quite difficult and offers guidance during the initial practice trials. Up to 40 practice trials are allowed.

INHIBIT is unrealistic in that no vehicle has reversing pedals. However, driving has many situations in which one’s usual response has to be changed, e.g., in response to a hazard on an icy road, hard braking would be disastrous. Offering examples, such as this, usually helps the examinee appreciate the rationale for INHIBIT.

**Report of Results**

**On-Line Reports**

Immediately following each procedure, tables and graphs of results are displayed and printed. For SELF-APPRaisal the position of the individual’s marker is converted to a number based on the mean and 96th percentile of the standardization group on the relevant measure of the DAS. For instance, speed of adaptation is reflected by the combined reaction time in INHIBIT, whereas impulse control is shown by wrong-pedal errors on INHIBIT.

The report for ON THE ROAD includes numbers of scrapes and crashes, mean deviation from center (“drift”), and standard deviation (“wobble”). These are available after each run through the course and can be used by the examiner to offer guidance and motivation.

For each of the reaction-time procedures (BRAKE!, DECIDE, and INHIBIT) tabular reports show a variety of statistics for the different components (choice, execution, combined, and resumption) of reaction time: number of trials, median, mean, minimum, maximum, range, standard deviation, percentage of trials within the time limit, percent errors (false alarm and, for DECIDE and INHIBIT, wrong pedal). Median reaction times are also analyzed according to pedal and side-of-display. Because the effects of brain injury are often lateralized, such differences may be substantial, whereas individuals in the standardization group show little difference in their response to the left and right sides. These laterality data are broken down by choice and execution components as well.

Median reaction times reflect the middle-most score when the reaction times are ranked. This measure “ignores” any extreme trials. The mean, however, reflects all the scores including extremes. Therefore if the mean is higher than the median, one should look further at the data for unusually high scores, which may reflect visual deficits (see Fig. 5), lapses of attention, absence seizures, or momentary sleep episodes. The standard deviation is also an index of inconsistency or variability in reaction time.

If there were trials on which the time limit was exceeded, means, standard deviations, and ranges are statistically inappropriate, and the value is reported as undefined (UDF).
his visual impairment. Even occasional lapses when driving would be cause for concern. Because occasional long trials would not appreciably affect the median reaction times, they are best seen in the graphic display.

Summary Report and Illustrative Case

Following completion of the full set of procedures, the DAS prints a summary report that includes graphic displays of the individual scores relative to the standardization group and to their own self-ratings, obtained initially. Illustrative data are derived from GA, a 59-year-old experienced driver without a significant history of violations or accidents who had sustained two or three cerebrovascular accidents. Following the last of these, he showed Parkinson-like symptoms and was using a number of medications for this condition. His use of his left arm was severely limited by spasticity and tremors. His right arm and leg were functional, though coordination and control were affected. Visually he had a binocular dysfunction for which he was undergoing optometric treatment. He had not been driving for several years but had returned to work part time and had developed alternative means of personal transport. However, he did continue to own several vehicles and wished to find out if there were any circumstances in which he could safely drive them.

The first page of his summary report (Fig. 6) summarizes the SELF-APPRaisal. Our subject rated himself as “average” in movement speed, ability to adapt quickly to new circumstances, consistency, concentration, and impulse control. He rated himself as slightly below average in field of vision and nearly as slow as the worst (but still safe) driver on the roadways. Nevertheless, he rated himself as reasonably capable of driving. Generally, his self-appraisal was cautious and reflected an awareness of his disabilities.

Page 2 of the report (Fig. 7) conveys the results of the tracking task, ON THE ROAD. For each measure, the subject's scores are tabulated by trial at the left. The normative group median (MDN) and 96th percentile (LIMIT) values are given. The graphic displays present the scores in a norm-referenced way, which allows one immediately to identify scores outside normal limits. The normal range (the range within which 96% of the normal group scored) corresponds to the solid line on the x-axis. GA's scores are denoted by the symbol 0.

To minimize the impact of tremors and discoordination, it was necessary to increase the steering "effort" to the maximum. Nevertheless, it is ap-
FIG. 6. Self-appraisal report for GA, a 59 year old with Parkinsonian symptoms following multiple cerebrovascular accidents.

parent that he had considerable difficulty keeping on the road—his "crashes," "scrapes," and standard deviation fell well beyond the upper normal limit. He also showed a tendency to deviate to the left of center; however, this was not so extreme as to place him beyond normal limits. The consistency of his performance did improve over the four trials.

Pages 3 and 4 (Figs. 8 and 9) of the report summarize the reaction-time findings.

Each measure is reported for the increasingly complex tasks: BRAKE!, DECIDE, and INHIBIT. Again the individual's scores are tabulated at the left, together with the norm group's median and 96th percentile in parentheses. The graphs are normalized to make it easy to see departures from the normal range.

FIG. 7. Visual motor tracking (ON THE ROAD) report for GA.

The fact that the execution times of the standardization group do not increase with increasing task complexity is noteworthy and substantiates that these times are reflective of motor function and not mental processing. In contrast, the choice times definitely increase with increasing complexity. According to findings of Milner (41) and van Zomer and Deelman (42,43), the typical head-injured person, or individuals with Alzheimer's dementia (44), may indeed match the speed of standardization group when the task is simple, i.e., on BRAKE!, but will exceed the normal limits dramatically as complexity increases.

GA's overall (combined) reaction times were as he suspected, slow; in fact he was well beyond the normal range on all tasks, regardless of difficulty. Breaking the response into choice and execution components revealed that the slowness was exclusively in the former, while the movement times were average or better. In Fig. 8, GA's self-appraisal has been converted into a predicted score using the control group's median and 96th percentile as the "average" and "worst" values. The resulting values are represented by the ? symbol. Although he did
not estimate the magnitude of his deficit, he was apt in pinpointing his difficulty in the decision (choice) component. He was not accurate in predicting his inconsistency. On BRAKE! he was slow to respond to stimuli on the right side, but he corrected this lateral imbalance on the more difficult reaction-time tasks.

On page 4 (Fig. 8) false alarm and wrong-pedal errors are reported (except for wrong-pedal errors for BRAKE! as they cannot occur on a simple reaction-time task). If the incidence of errors (false alarms and wrong pedal presses) is much greater than the standardization group, one must be cautious in interpreting the reaction-time data, which is why during practice all attempts should be made to discourage errors.

The clinician has to observe carefully and judge the reason for false alarm errors. In some cases wrong pedal errors may reflect a criterion shift to maximize speed at the expense of accuracy. More significant clinically are persons with poor impulse control functions who cannot contain their errors. These issues were not problematic for GA, whose errors were well within the range of the standardization group.

Finally at the bottom of page 4 the examiner summarizes clinical impressions of different aspects of the performance using ratings that integrate clinical impressions with the different performance measures.

"Visuo-motor (pursuit tracking)" reflects overall performance on ON THE ROAD, especially as related to eye-hand coordination.

"Movement speed" is reflected in the execution component of reaction time and times on the simple reaction-time task (BRAKE!).

"Speed of information processing" is reflected in the choice component of reaction time and times on the more complex tasks (DECRIDE and INHIBIT).
IV. SUMMARY

A. AREAS OF CONCERN

1. Steerling. GA used his right upper extremity only, as he had a significant tremor in his left arm, rendering it unable to serve even to steady the wheel. Even so, it was necessary to adjust the tension on the wheel so that it was 'very heavy.' Nevertheless, he had difficulty controlling the wheel smoothly, sometimes overcorrecting and undercorrecting. On a few occasions where there was a need to turn in one direction, he would turn in the opposite direction. These tendencies could be disheartening in a sensitive vehicle; while they might be tolerable with a highly 'forgiving' one.

2. Mental processing efficiency. As the tasks became more complex, GA's performance deteriorated more than we usually observe. His reaction times on the visual field screening were about 0.3 sec greater than might have been expected.

3. Inconsistency was noted on dynamic visual field screening without a clear pattern. It was possible to distract him with conversation, especially as he seemed to need to compensate for his hearing impairment by lipreading.

4. Pedal control was fair and should be observed in on-road in-vehicle testing.

5. Changing visual status, associated with vertical imbalance (right hyperphoria) and double vision at times. Squinting, or otherwise occluding one eye would correct this problem, but will introduce a new problem—impaired spatial sense. It is important for GA to appreciate the consequences of this. It might be enlightening for him to have some supervised driving with one eye covered intentionally.

6. Changing medical status. GA may have Parkinson’s, a 'progressive' disorder. If he does, he has to realize that the question is not whether he should abandon driving, but when should he do so. It will be important for him to establish objective guidelines to signal the need for re-evaluation or discontinuing driving.

B. STRENGTHS

1. GA is an experienced driver and continues to have an appreciation of safety issues. His own experience and good record as a driver give him a good foundation for resuming driving.

2. GA is conscientious and receptive to input from others regarding the advisability of his driving.

3. Driving is an option, not a requirement, for him. He is both willing and able to limit himself to times and circumstances in which he is most likely to be safe.

4. GA is a quiet learner and would capitalize on using his intellect to drive defensively and reduce his exposure to risk.

5. His endurance appears to be good. Fatigue would not compromise his driving ability.

FIG. 10. Examiner’s conclusions for GA.

"Consistency of performance" corresponds to low standard deviations on ON THE ROAD, BRAKE!, DECIDE, and INHIBIT. Variability is also shown by erratic patterns of performance on graphs or by observation of "wobbly" steering on ON THE ROAD.

"Laterality (unequal response to both sides)" problems are shown by a tendency to deviate to one side or the other in pursuit tracking (ON THE ROAD) or discrepancies in responding to stimuli on the right or left side of the display in the reaction-time tasks. Lateral differences in speed of response to the brake (left) and horn (right) would also be included in this category. The examiner should note if the discrepancy is motor or sensory.

"Acquisition (learning) of procedures" is based on the examiner's impressions of how much instruction and practice was necessary to achieve an optimal level of performance.

"Self-modulation (impulse control)" is shown by an ability to inhibit false alarms, and, especially, inhibition of commission of wrong-pedal errors.

"Meta-cognition (self-appraisal)" is reflected by the correspondence between the individual's performance and self-ratings, as well as responses to questions about current driving ability. The examiner should evaluate general level of confidence or caution as well as the degree of specificity in the correspondence between self-ratings of different performance measures.

On page 5 of the summary report (Fig. 10) we have detailed conclusions for GA, organized by areas of concern and strengths. Recommendations and cautionary statements are on page 6 (Fig. 11).

GA's experience with the DAS clarified and reinforced his own concerns about his driving. It also helped to focus observations during subsequent on-the-road training. After a series of lessons, he and the driver trainer agreed that he could not perform with enough consistency to be safe. Although dis-
1. Recommendations

1. Not yet ready to resume independent driving. His impaired mental processing speed, steering, and other problems which could significantly increase his risk.

2. Rehabilitation-oriented specialized on-the-road evaluation. Before resuming driving, it is important that GA pass a road test given in a facility which is experienced in assessing the capabilities of persons who have had acquired brain injury, including stroke. One such facility is at __________. Mr. _______ is an experienced driving evaluator/instructor there. I spoke with him at GA's request. He advised me that it would probably be necessary to undergo evaluation by a physician and occupational therapist there, and that there is often a waiting list. Mr. _______ will send the appropriate forms to GA.

3. Defensive driver course. Although GA has good safety awareness, it would be helpful for him to have a defensive driving refresher course. These courses are offered around the state, e.g., National Safety Council (800-950-3434), National Traffic Safety Institute (800-334-1444), American Association of Retired Persons, AAA.

4. Supervised driving. When ready to resume driving, GA will need to practice, at first with a licensed driver educator in a vehicle with dual controls. Mr. _______ at _________ might be helpful.

5. Vehicle modifications might be helpful, especially an adjustment of the tension of the steering wheel and a spinner knob.

X

[Signature]

1. The driving advisement system is intended for use by clinicians charged with evaluating and advising individuals concerning their potential for safe driving.

2. It addresses only as aspect—condition—of safe driving. Comprehensive pre-driving assessment must address other domains, including neurologic, motoric and sensory functions, especially vision.

3. No one can guarantee that an individual who does well on these tests will be accident-free, and no such assurance is implied by a favorable recommendation.

4. The Department of Motor Vehicles of the State of Louisiana has the exclusive authority to grant and withdraw driving privileges.

FIG. 11. Examiner's recommendations and cautionary statements for GA.

appointed, he deferred his driving plans, satisfied that every possible effort had been made. The DAS helped him begin to come to terms with this reality.

Preliminary Psychometric Findings for the DAS

Standardization

In order to compare the performance of various clinical populations—the survivors of brain injury for whom this was intended—as well as others, such as the elderly for whom it might be useful, we have DAS performance data from a comparison group of over 60 licensed drivers. These individuals are of different ages ranging from 16 to 86 years old.

For assessing brain-injury survivors who would resume driving, the ideal standardization group would be a group of survivors of brain injury who have resumed driving and maintained accident- and violation-free records for several years. Of course these people would have to be driving, as not all persons who achieve reinstatement of licensure actually use it (1). Practically, it may be difficult to accumulate a large group like this.

Because the performance of this group is reflected in the normative information included on the clinical reporting form, it will not be reproduced here. Review of the data shows them to be highly consistent and internally valid (e.g., reaction times are consistently longer for more complex tasks.)

Validation

Our first validation study (33) involved a group of 60 traumatic brain injury (TBI) and cerebrovascular accident (CVA) survivors given the DAS in addition to a comprehensive pre-driving evaluation in which the ultimate pass/fail decision was based on the non-DAS measures, including the Porto Clinic Glare and on-the-road assessment, when deemed safe. With the pass/fail decision as a criterion, the DAS measures actually correlated slightly better than the Porto Clinic Glare.

Further data collection (34) has focused on concurrent validation using the DAS and other accepted procedures. Concurrent validation data for the DAS with the Driver Performance Test (16) and the Doron simulator (23) have been collected, and initial analyses show the DAS and the Doron simulator to correlate well with the outcome of a comprehensive evaluation. However, the DAS measures addressed a broader range of factors than the Doron simulator.
Figure 12 shows data from two successive normative samples and two independent clinical samples ("SS" and "AC"). The clinical samples have been subdivided based on outcome (pass or fail) of the overall predriving evaluation. In Figure 12 the performance of these groups is shown for percent errors on the most complex reaction-time task, INHIBIT. The two normative samples were virtually identical and made fewer errors than any of the clinical samples. The clinical groups who passed made slightly more errors than the norms, whereas those who failed made substantially more errors. Comparable clinical groups were essentially the same, bearing out the reliability of this DAS measure.

Although predictive validity studies, in which individuals are followed up after assessment, would seem ideal, such studies are fraught with difficulties. For example, only individuals who "pass" an assessment are likely to be given the opportunity to drive, so that follow-up data will only be available on them. In other words, we would not know what would have happened had individuals who "failed" the assessment procedures been allowed to drive anyway. It will therefore be difficult to know if the assessment procedures are oversensitive. Generally, it is difficult to amass the sample sizes necessary for meaningful comparisons of safety indicators, as accidents are relatively rare events even in patently unsafe drivers. Further, some bias may occur toward reduced reporting of accidents by brain-injury survivors, considering that this may jeopardize their licensure or insurance rates.

Nevertheless, we were able to contact 49 of the 60 persons in our initial validation study 1 year later (35). DAS measures correlated meaningfully with
such indicators as reported miles driven and self-restriction (e.g., avoiding night and highway driving). Accidents and violations were too infrequent to permit analysis.

Discussion

Another application of the DAS is to help evaluate the need for adaptive equipment to overcome certain physical disabilities. In GA's case we were able to demonstrate that increased tension on the steering wheel helps reduce the effects of his tremors on steering stability. In other cases we have been able to determine if a weak or poorly controlled leg is sufficiently quick and reliable, or whether the other foot would be much better. By demonstrating that performance is enhanced when the pedals are operated by a hand, one can show adequate cognitive ability and the potential value of either hand controls or pedal adaptations.

Through the DAS we have sought to capitalize on computer technology to help persons with possible cognitive impairments to understand their strengths and liabilities as drivers so that they can decide whether and how they should drive, and if not, whether and what training (and modifications) might help. The DAS is more than a convenience for the clinician because it brings real-time and precise measurement into the evaluation process. At the same time it brings out performance that has a convincing relationship to driving with explicit graphic feedback that demonstrates how the individual compares with noninjured drivers.

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The authors' responsibilities include: Mr. Beattie developed the software and Dr. Mandriota the hardware. Dr. Gianutso has had primary responsibility for the design, implementation, and testing of the DAS, as well as the preparation of this report.

REFERENCES

5. AAA Traffic Safety Dept. AAA Automatic Brake Reaction Timer. (1000 AAA Drive, Heathlow, FL 32746-5063.)
25. Forbes TW, Nolan RO, Schmidt FL, Vandasall FE. Driver
performance measurement based on dynamic driver behavior
patterns in rural, urban, suburban and freeway traffic.
D, Smith D, Woodward A. Michigan road test implementa-
tion project. Final report. Pilot implementation of the
27. Wright PG, Hatten LJ, Perkins WA. The implementation of
a 'Michigan' style driving test in New Zealand—a prelimi-
nary evaluation. Wellington, New Zealand: Ministry of
28. Hopewell CA, van Zomeren AH. Neuropsychological aspects
of motor vehicle operation. In: Tupper D, Ciccone K, eds.
Neuropsychology of every-day life. Boston, MA: Kluever,
29. van Zomeren AH, Brouwer WH, Minderhoud JM. Acquired
brain damage and driving: a review. Arch Phys Med Rehabil
1987;68:697-705.
30. van Zomeren AH, Brouwer WH, Rottengatter JA, Snoek
JW. Fitness to drive a car after recovery from severe head
31. Nouri FM, Tinson DJ, Lincoln NB. Cognitive ability and
32. Gawron VJ, Ramney TA. The effects of alcohol dosing on
driving performance on a closed course and in a driving
simulator. Ergonomics 1988;31:1219-44.
33. Gianutsos R, Campbell A. A computer-assisted Driving Ad-
visement System (DAS) for addressing underlying cogni-
tive skills necessary for safe driving. Louisville, KY: Asso-
ciation of Driver Educators for the Disabled, 1988. (Paper
presented at annual meeting.)
34. Gianutsos R, Campbell A. Driving advisement: different
approaches described and evaluated. Cincinnati, OH:
American Occupational Therapy Association, 1991. (Paper
presented at annual meeting.)
35. Gianutsos R, Campbell A. Concurrent and predictive va-

didity of the Driving Advisement System (DAS). Grand
Rapids, MI: Association of Driver Educators for the Dis-
abled, 1988. (Paper presented at annual meeting.)
36. van Zomeren AH. Reaction time and attention after closed
head injury. Lisse, The Netherlands: Swets & Zeitlinger
B.V., 1981.
37. Evans L. Older driver involvement in fatal and severe traffic
38. Williams AF, Carsten O. Driver age and crash involvement.
39. Rossi DG, Flint SJ. An evaluation of mature driver perfor-
mance. Traffic Safety Bureau, Transportation Programs Di-
vision, New Mexico Highway and Transportation Depart-
ment, Santa Fe, NM, 1988.
40. Gianutsos R. Computer programs for cognitive rehabilita-
tion, vol. 6. Driving advisement system [computer program].
Bayport, NY 11705.)
41. Milner AD. Chronometric analysis in neuropsychology. Neu-
42. van Zomeren AH, Deelman BG. Differential effects of simple
and choice reaction time after closed head injury. Clin Neu-
43. van Zomeren AH, Deelman BG. Long term recovery of vi-

sual reaction time after closed head injury. J Neurol Neu-
44. Mahurin RK, Pirozzolo FJ. Chronometric analysis: clinical
applications in aging and dementia. Dev Neuropsychol 1986;
2:345-62.