The Neurocognitive Driving Test: Applying Technology to the Assessment of Driving Ability Following Brain Injury

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Objective: To compare the Neurocognitive Driving Test (NDT) with an established driving assessment method. Study Design: A prospective matched-control study. Participants: Fifteen adult volunteers with acquired brain injury (ABI), aged 21–59 years, referred for a driving evaluation and 15 healthy control (HC) participants. Methods: Individuals with ABI were administered the NDT and a traditional hospital-based driving evaluation. An overall performance score was calculated and used to rank order driving ability. HCs were administered the NDT to establish NDT performance range. Main Outcome Measures: Overall performance on the NDT; overall performance on a comprehensive hospital-based evaluation. Results: Comparison of the rank orders of driving ability for participants with ABI revealed a significant Spearman correlation. NDT scores discriminated between individuals with ABI who passed the driving evaluation and those who failed. Conclusions: Results help establish the potential utility of the NDT for evaluating driving ability in persons with ABI.

The physical and cognitive impairments that follow acquired brain injury (ABI) can make driving an automobile difficult, and this limitation often disrupts vocational, social, and domestic activities. Among individuals with brain injury, the cessation of driving has been related to difficulties in employment (Devani Serio & Devens, 1994), higher incidence of depression (Legh-Smith, Wade, & Langton Hewer, 1986; Marottoli, De Loen, & Glass, 1997), and poor social integration (Dawson & Chipman, 1995). Similarly, research examining loss of social autonomy following traumatic brain injury has identified driving as the third most impaired social ability postinjury (Mazaux et al., 1997). The privilege of driving serves as a gateway to independent functioning but also poses potential dangers to the driver and members of the community. As such, evaluation of driving ability following ABI requires careful analysis of the individual’s cognitive, physical, and behavioral capacities.

Rehabilitation specialists are often asked to determine capacity to return to driving following ABI. Protocols for making this determination can include neuropsychological tests, performance on behind-the-wheel evaluations, and driving simulator performance (Croft & Jones, 1987; Fox, Bowden, & Smith, 1998; Galski, Bruno, & Ehle, 1992; Van Zomeren, Brouwer, & Mindenhoud, 1987). Some recommendations regarding the use of these and other protocols have been presented (e.g., Association for Driver Rehabilitation Specialists). However, the variability in state legislation regulating driving assessment of medical populations and in professionals charged with the responsibility of determining driving capacity (e.g., psychologist, physical and occupational therapists, physicians) has hindered the identification of a nationally accepted standardized clinical driving assessment method. This is remarkable, considering that 78% of all survivors of ABI seek to regain driving privileges after injury (Fisk, Schneider, & Novack, 1998), and of these, the majority (84%) report returning to driving on a daily basis.

A critical review of the driving assessment literature reveals research that is varied in both its sources and claims. For example, the Pennsylvania state legislature has maintained that visual scanning and reaction time, combined with knowledge of traffic laws, are the best predictors of driving ability. Other researchers, however, have indicated that these variables are not predictive of accident risk (Hopewell & Van Zomeren, 1990). As a result, much controversy remains regarding the most appropriate method for determining driving capacity following ABI.

Neuropsychological assessment has received considerable atten-
tion in driving evaluations (Brooke, Questad, Patterson, & Valois, 1992; Galski, Bruno, & Ehle, 1993; Gouvier et al., 1989; Jones, Giddon, & Croft, 1983; Korteling & Kaptein, 1996; Sivak, Olson, Kewman, Won, & Henson, 1981). Investigators have reported that performance on tests such as the Trail Making Test (Galski et al., 1993; McKenna, 1998; Van Zomeren et al., 1987) and the Wechsler Adult Intelligence Scale Digit Symbol (Lundqvist et al., 1997) and Block Design subtests (Galski et al., 1993) is predictive of pass/fail performance on behind-the-wheel evaluations. Although the results of these studies have been highly variable (Korteling & Kaptein, 1996), they have led to the identification of specific cognitive skills deemed important for driving (e.g., visual perception, divided attention). However, it remains unclear how neuro-psychological performance can meaningfully characterize functional driving ability (Wilson, 1993).

Researchers have also developed computerized tasks that attempt to assess specific skills believed to be important in driving. For example, Gianutsos (1994) introduced the Elemental Driving Simulator, a PC-based driving simulator designed to evaluate abilities such as simultaneous information processing, dealing with complexity, mental flexibility, impulse control, and measures of an individual’s ability to estimate their own performance (metacognition). More recently, Ball and Owsley (1993) introduced the Useful Field of View, a computerized task designed to measure visual attention and cognitive processing. Analysis of this program has revealed positive correlations with risk of accident involvement among elderly clinical populations (Ball, Owsley, Sloane, Roenker, & Bruni, 1993). Others have used simulator-based systems that emphasize evaluation of the temporal detection of driving “vectors” (i.e., other cars, people, road signs; Schiff, Arnone, & Cross, 1994). Although these systems may appear to have greater face validity, their limitation, similar to that seen in traditional film/video-based driving simulators, is a lack of substantial interaction between participants and the environment. That is, although driving scenes that elicit measurable responses from participants are presented, the actions or responses of the participant (e.g., turning) do not alter the course of the scenario, resulting in a lack of immediate feedback. Traditional driving simulators have been incorporated by some for driving assessment (Galski et al., 1992; Schiff et al., 1994); however, there is little evidence that simulators do anything more than assess basic driver operational skills, such as steering, braking, and using appropriate turn signals (Lings & Jensen, 1991; Lovsund, Hedin, & Tornros, 1991).

Although there are a myriad of driver assessment measures available, evaluation of behind-the-wheel performance remains the “gold standard” in driving assessment (Brooke et al., 1992; Fox et al., 1998). Typically, these evaluations involve having individuals drive on preselected routes while being rated on specific driving behaviors by a trained evaluator. Unfortunately, selection of the behind-the-wheel route can vary from evaluator to evaluator. For example, some are limited to closed driving areas (e.g., parking lots), whereas others may be more comprehensive and include a variety of driving conditions (e.g., parking lot, highway, and residential areas). Furthermore, there is a risk of high subjectivity in rating driving behavior, as not all evaluators use a structured checklist or other methods of quantifying driving behaviors observed during the behind-the-wheel evaluation. Not surprisingly, to reduce risk of injury (for both patient and evaluator), an effort is made to avoid challenging driving situations (e.g., night driving, congested traffic, or emergency situations). However, it has been argued that complex situations may be most predictive of driving ability (Fox et al., 1998).

In summary, current methods for determining driving capacity include the assessment of individualized skills (e.g., reaction time, visual perception, cognitive skills), simulated driving, and behind-the-wheel evaluations. Attempts to develop comprehensive driver evaluations have resulted in complex multilevel systems that are not practical or cost effective for many clinicians or facilities. These methods also have significant shortcomings in their objectivity, ecological validity, theoretical basis, and practicality. First, methods should require the consistent incorporation of objective measures of driving behavior. Although clinical observation of driving performance remains an important tool, empirical measures of individual performance should be an integral part of driver analysis and could help further elucidate the cognitive demands of driving, allow for increased consistency across evaluators, and help establish the reliability and validity of these methods. Second, the inclusion of ecologically valid stimuli, specifically more complex and challenging driving situations, may increase our ability to predict real-life driving behavior. Although some methods, such as the clinical behind-the-wheel evaluation, have strong face validity, further research is needed examining the ability of these methods to predict impairment in everyday driving. Third, the incorporation of existing theoretical perspectives could enhance the development of assessment paradigms. For example, Michon (1985) proposed a hierarchical model of car driving, which incorporated strategic, tactical, and operational levels of tasks. To date, only portions of this model have been used in driving assessment (Gianutsos, 1994; Hopewell & Van Zomeren, 1990; Van Zomeren et al., 1987). Such a theoretical foundation could help to provide stability and direction in this rapidly developing area of research. Finally, the issue of cost effectiveness must be considered in the development of any new assessment protocol. The need to minimize current costs of driving evaluations is particularly important, as driving assessment is currently an out-of-pocket expense for most ABI survivors (Rosenthal, Griffith, Kreutzer, & Pentland, 1999).

Development of the Neurocognitive Driving Test (NDT)

The NDT is a computer-based driving assessment protocol designed to address some of the current limitations in driving assessment. The NDT is a Macintosh-based computer program that was developed through the use of PowerLaboratory software (Chute & Westall, 1996) and was based on Michon’s (1985) theoretical model of driving behavior. Specifically, Michon proposed that all tasks related to driving can be organized into three hierarchical levels: the strategic level, the tactical level, and the operational level. Briefly, the strategic level consists of driving behaviors, such as route determination, day and time of the journey, costs, and other executive decisions. The tactical level includes driving adjustment behaviors, such as adjusting speed to the driving environment and switching on headlights when visibility is reduced. In addition, this level includes operator judgments, such as when to pass another vehicle, how to negotiate a curve, and how to handle emergency situations. The lowest level, the operational level, involves the common actions and decisions of driving that are made by the vehicle operator under constant time pressure,
including decisions in steering, braking, perception of driving situation, and the use of mirrors and controls.

The five sections of the NDT, designed to measure driving behaviors of the three levels proposed by Michon (1985), include self-evaluation questions, predriving questions, simple and choice reaction-time tasks, driving scenarios, and a visual task (see Table 1 for descriptions). For each task, a measure of error and a measure of time to respond (i.e., latency) are automatically recorded by the computer. Initial pilot testing was conducted to determine administration and scoring protocols.

A total performance score (NDT total score) was calculated incorporating the individual latency and error variables of four out of the five NDT tasks. Responses to the self-evaluation questions were not included in the NDT total score, and an error variable for the predriving questions was not calculated, given the broad spectrum of responses generated. To ensure equal weighting of each variable into the NDT total score, values were converted to a range of 0 to 1. Conversion was completed by dividing individual values by highest possible errors for that variable, resulting in a score of 1 for worst performance and 0 for best performance. A total sum of the variables was then calculated, yielding the NDT total score, which ranged from 1.2 (best score) to 6.0 (worst score), based on findings from our pilot sample.

Purpose of the Study

The purposes of this study were (a) to compare the NDT to a comprehensive hospital-based driving evaluation in the assessment of driving performance in individuals with ABI and (b) to contrast the NDT performance of adults with ABI who passed a driver evaluation to that of adults with ABI who failed a driver evaluation and of control participants.

Method

Participants

The participants were 15 adults with ABI and 15 age-, gender-, and driving experience-matched healthy control (HC) participants. All participants with ABI were recruited from incoming referrals for driving evaluations at the MossRehab Driving School, which, for nearly 25 years, has provided driving evaluations, driver training, and assessment for adaptive driver’s equipment for individuals with a wide variety of disabilities (e.g., traumatic brain injury, stroke, multiple sclerosis). Following completion of the clinical evaluation, participants were offered the opportunity to participate in the study. Participants were informed that participation was voluntary, would not affect their current driving status, and did not include monetary compensation. Prior to initiation of testing, all participants completed a consent form approved by the Institutional Review Board.

Limited medical information was available for participants with ABI, given the high variability of time of and source of referral for driving evaluation. For ABI participants, records provided to the driving program were used to verify loss of consciousness and diagnosis of brain injury. Eight participants were injured in motor vehicle accidents, 4 were involved in other types of accidents (e.g., struck on the head), and 3 underwent surgical interventions for neurological abnormalities (e.g., brain tumor, aneurysm). Control participants were recruited from staff and students of a local university. No statistically significant differences in age, $t(29) = -0.18$, ns; gender, $\chi^2(1, N = 30) = 0.95$, ns; education, $t(29) = -0.42$, ns; or years of driving experience, $t(29) = -0.18$, ns, were observed between the two groups. A summary of the participant characteristics can be found in Table 2.

All participants spoke English as their primary language, and all but 2 expressed moderate familiarity with computers. All participants were also required to be independent of the need for assistive driving devices at the time of the evaluation. Those with a history of psychiatric illness, significant substance abuse, neurological degeneration or disease, or previous neurologic injury were excluded from the study.

Measures

Two measures were used to assess driving ability: (a) overall performance on the NDT (see description above), as determined by the NDT total score, and (b) overall performance on a comprehensive hospital-based evaluation that included a visual acuity and peripheral vision task—the Motor-Free Visual Perceptual Test—and a 30-min behind-the-wheel evaluation. The evaluation was completed by the same occupational therapist, who specialized in driving assessment and was certified by the Association for Driver’s Educators for the Disabled.

Procedure

All participants with ABI first completed the hospital-based driving evaluation. For each participant, at the end of the hospital-based driving evaluation, the instructor/evaluator completed a driver evaluation form.

Table 1

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
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<tbody>
<tr>
<td>Self-evaluation questions</td>
<td>Five self-report questions on which participants rate their driving ability on a 5-point scale.</td>
</tr>
<tr>
<td>Predriving questions</td>
<td>Series of 12 open-ended and multiple-choice questions assessing an individual’s ability to identify information needed prior to engaging in driving (e.g., check gas in car, have proper documentation).</td>
</tr>
<tr>
<td>Simple and choice reaction-time tasks</td>
<td>Total of 24 counterbalanced trials, 12 simple and 12 choice measures. Participants respond via foot pedal to color stimuli presented through a modified photograph of a traffic light. Latency and total errors are recorded.</td>
</tr>
<tr>
<td>Driving scenarios</td>
<td>Simulated driving scenarios engineered to measure driving ability by requiring participants to drive through three scenarios using a steering wheel and foot pedals. Driving situations include emergency, verbal directions, and written directions. Initiation time (measure of time required for driver to reengage in the act of driving after stop stimulus has been presented) and total errors are recorded.</td>
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<tr>
<td>Visual task</td>
<td>Assesses gross field cuts and visual inattention. Incorporates 40 trials, with measures for both peripheral and focal visual field errors. Latency and errors are recorded.</td>
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</table>
After all hospital-based driving evaluations were completed, the instructor/evaluator ranked the performance of participants with ABI from best to worst (1–15). In addition, consistent with standard procedures, a pass or fail grade was assigned to participants with ABI at the completion of the hospital-based evaluation. To minimize bias, the experimenter was blind to the results of the hospital-based driving evaluation. Following completion of the hospital-based driving evaluation, participants with ABI were scheduled for a one-time session for administration of the NDT. All testing sessions included completion of a brief history questionnaire. For administration of the NDT, participants were seated at a MacIntosh computer with attached steering wheel and foot pedals and a 19-in. (48.26-cm) monitor, which was adjusted to eye level (see Figure 1). At completion of the NDT, a rank order of driving ability from best to worst (1–15) was generated for all participants with ABI on the basis of the NDT total score performance.

A Spearman rank-order correlation was calculated to compare the rank order generated by the NDT total score and the rank order provided by hospital-based driving evaluation. HC participants were seen for only one testing session, which included completion of a brief history questionnaire and the same administration of the NDT.

**Results**

Comparisons of the rank order of driving ability as determined by the NDT total score and the hospital-based driving evaluation revealed a significant relationship between the two measures (Spearman rank-order $r = .743$, $p < .01$; see Table 3).

To examine the NDT’s ability to distinguish participants with ABI who passed the hospital-based driving evaluation (ABI Pass; $n = 11$) from those who failed (ABI Fail; $n = 4$), we calculated a cutoff score equal to two standard deviations from the control group mean (cutoff = 4.32). The mean NDT total score for the ABI Pass group was 3.78 ($SD = 0.96$), the ABI Fail group obtained a mean NDT total score of 5.31 ($SD = 0.22$), and the HC group obtained a mean NDT total score of 3.24 ($SD = 0.54$; see Figure 2). All patients failing the hospital-based driving evaluation exceeded the two standard deviation cutoff score. In addition, it is worth noting for those passing the hospital evaluation that the NDT cutoff score accurately categorized patients 72% of the time; only 3 individuals passing the hospital-based driving evaluation scored above the cutoff of 4.32 (see Figure 3). As noted, the NDT correctly matched the top 2 participants ranked by the hospital evaluator and placed the 4 individuals who failed the hospital-based driving evaluation at the lower end of the rank order. Overall, the NDT cutoff score successfully categorized 80% of all participants with ABI.

**Table 2**

<table>
<thead>
<tr>
<th>Demographic variable</th>
<th>ABI</th>
<th>HC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n$</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Age (years)</td>
<td>38.6</td>
<td>33.2</td>
</tr>
<tr>
<td>$M$</td>
<td>10.8</td>
<td>6.8</td>
</tr>
<tr>
<td>Range</td>
<td>21–59</td>
<td>23–45</td>
</tr>
<tr>
<td>Education (years)</td>
<td>14.3</td>
<td>15.0</td>
</tr>
<tr>
<td>$M$</td>
<td>1.9</td>
<td>2.4</td>
</tr>
<tr>
<td>Range</td>
<td>12–18</td>
<td>12–18</td>
</tr>
<tr>
<td>Time postinjury (months)</td>
<td>23.8</td>
<td>22.8</td>
</tr>
<tr>
<td>$M$</td>
<td>4–96</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>Male (%)</td>
<td>10 (75)</td>
</tr>
<tr>
<td>Female (%)</td>
<td>5 (25)</td>
<td>6 (40)</td>
</tr>
<tr>
<td>Driving experience (years)</td>
<td>21.0</td>
<td>16.2</td>
</tr>
<tr>
<td>$M$</td>
<td>9.7</td>
<td>6.6</td>
</tr>
<tr>
<td>Range</td>
<td>3–34</td>
<td>5–28</td>
</tr>
</tbody>
</table>

Note. ABI = acquired brain injury group; HC = healthy control group.

**Figure 1.** Person sitting at the Neurocognitive Driving Test.
Discussion

The current study was designed to compare a newly developed computer-based driving assessment tool, the NDT, with the current “gold standard” of driver assessment, a comprehensive hospital-based driving evaluation. The findings revealed a significant relationship between the two measures, suggesting that both programs are targeting similar skills, which at present serve as the criteria for an individual’s return to driving after an ABI. Furthermore, the findings support the NDT’s ability to discriminate between those individuals who passed the hospital-based driving evaluation and those who failed and consequently were not eligible for relicensing. Specifically, a derived NDT cutoff score (based on HC performance) demonstrated sensitivity for detecting driving impairment and accurately categorized 80% of the entire brain-injured sample.

Although these initial findings are encouraging, more research is needed to determine the utility of this new measure. In particular, future investigations should include larger sample sizes, with greater diversity in the nature of neurological impairment (e.g., multiple sclerosis, degenerative diseases) and more clearly defined characteristics of the sample. Comparison of NDT performance to other tasks thought to measure driving ability (e.g., neuropsychological measures) would also help further validate its use. Although the NDT appears to be sensitive to driver impairment, analysis of driver behavior through the use of cutoff scores does not delineate the discrete cognitive skills required for driving, nor does it identify the specific reasons for failure in any individual case. Inclusion of neuropsychological measures and medical characteristics may better specify the cognitive impairments most relevant to NDT performance.

The continued development and research of the NDT may be valuable, given its unique attempt to address many limitations in current protocols—its capacity to offer objectivity, incorporation of ecologically valid stimuli, and a low-cost user-friendly format. In summary, this study represents the first evaluation of the NDT, and the results provide initial support for the utility of this new protocol for evaluating driving ability of persons with ABI. With further validation, the NDT may serve as a supplemental assessment tool (i.e., screening measure) and to enhance driving assessment and inform treatment planning.

References


Gianutsos, R. (1994). Driving advisement with the elemental driving

Figure 2. Comparison of Neurocognitive Driving Test (NDT) total scores across the three groups. HC = healthy controls; ABI Pass = those with acquired brain injury who passed the hospital-based evaluation; ABI Fail = those with acquired brain injury who failed the hospital-based evaluation.

<table>
<thead>
<tr>
<th>PASS</th>
<th>FAIL</th>
</tr>
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<tbody>
<tr>
<td>Hospital Evaluation</td>
<td>11</td>
</tr>
<tr>
<td>NDT</td>
<td>8</td>
</tr>
</tbody>
</table>

Figure 3. Comparison of pass/fail driving performance of the two assessment measures. NDT = Neurocognitive Driving Test.

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