

Divided Attention and Driving: A Pilot Study Using Virtual Reality Technology

Background: Virtual reality (VR) was used to investigate the influence of divided attention (simple versus complex) on driving performance (speed control). **Design:** Three individuals with traumatic brain injury (TBI) and three healthy controls (HC), matched for age, education, and gender, were examined. **Results:** Preliminary results revealed no differences on driving speed between TBI and HC. In contrast, TBI subjects demonstrated a greater number of errors on a secondary task performed while driving. **Conclusion:** The findings suggest that VR may provide an innovative medium for direct evaluation of basic cognitive functions (ie, divided attention) and its impact on everyday tasks (ie, driving) not previously available through traditional neuropsychological measures. Key words: *brain injured, divided attention, driving, virtual reality*

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TRAUMATIC BRAIN INJURY (TBI) can result in a range of cognitive, behavioral, and physical impairments that can contribute to a decline in the ability to carry out everyday activities. The ability to drive an automobile is one activity that can be affected by these disabilities and one that is critical to maintaining independence. Prior studies have demonstrated that impairments on such cognitive skills as visual scanning, attention, information processing speed, visuospatial skills, and various executive functions can result in impaired driving skills and abilities.¹⁻⁵ The presence of deficits within these cognitive domains has been well documented in TBI.^{6,7}

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As such, it is important to understand how specific cognitive impairments affect driving capacity.

The driver's lack of attention has been frequently cited as a major cause of motor vehicle accidents.^{8,9} Although it should be noted that attention encompasses a wide variety of definitions, generally it can be broadly defined as the ability of the individual to process information from the environment or the capability of receiving and processing stimuli. Various aspects of attention have been identified in the literature, including immediate attention span, selective or focused attention, sustained attention or vigilance, divided attention, and alternating attention or attentional control.^{10,11}

In particular, divided attention, which specifically requires the ability to process and/or respond to information while simultaneously conducting more than one task at a time, has been commonly deemed as relevant to driving capacity. In TBI, impaired performance on tasks requiring divided attention has been documented.¹¹⁻¹⁵

Early studies with healthy individuals defined the ability to simultaneously process information from more than one source as a requirement for driving.^{14,15} Functionally, driving demands that the individual is required to focus on multiple tasks at the same time. Examples of "real-life" divided attention demands while driving can include continuously monitoring information from the road scene while being able to scan the environment for potential hazards, attending to multiple elements of information, and shifting attention back and forth as needed (ie, monitoring information from the dashboard while attending to road conditions).

The relationship between impairment of divided attention and decreased driving capacity has been documented in a variety of clinical populations, including drivers with Alzheimer's disease,^{16,17} stroke,¹⁸ and

TBI.¹⁹⁻²² In such studies, a correlation between impaired performance on neuropsychological measures, such as the Trail Making Test, WAIS-R Digit Span and Digit Symbol, and Pass/Fail performance on behind-the-wheel evaluations have been observed.²³ However, as is the case with many neuropsychological measures, these traditional measures have both poor face validity and ecological validity.²⁴ Little work has been done to directly measure specific driving performance requiring divided attention with traditional neuropsychological measures of divided attention. A direct examination of divided attention and driving remains to be conducted.

VIRTUAL REALITY TECHNOLOGY

Virtual reality (VR) is an emerging technology that allows individuals to "interact" with and become "immersed" in a three-dimensional computer-generated environment. Through its capacity to create dynamic, multisensory, "real-life" stimulus environments, within which all behavioral responding can be recorded, VR potentially offers clinical tools that are not available using traditional neuropsychological methods. To date, VR has been successfully integrated into several aspects of medicine, including the treatment of phobias,²⁵ pain distraction,²⁶ the training of surgeons,²⁷ and the education of patients.²⁸ Not surprisingly, within rehabilitation medicine, clinicians and researchers are also beginning to recognize VR's potential as a new tool for the study, assessment, and rehabilitation of cognitive processes.²⁹⁻³² In addition, a number of researchers have advocated for using VR for the evaluation and retraining of functional activities of daily living, such as the use of public transportation,³³ meal preparation,³⁴ and driving an automobile.³² Results from these initial studies indicate that the use of VR has several advantages

over traditional neuropsychological assessment and retraining protocols, including the direct evaluation of complex behaviors in ecologically valid environments, objective evaluation of complex behaviors, and the opportunity to present challenging conditions while maintaining the safety of both the clinician and patient.

Given these advantages, VR can provide a new mechanism for objectively quantifying driving skills and more directly examining the impact of specific cognitive functions (ie, divided attention) on driving performance. The purpose of this pilot study was to begin to examine the benefits offered through VR to investigate the purported relationship between divided attention and driving performance among persons with cognitive impairment. Specifically, using a VR-based driving environment, the influence of various aspects of divided attention (ie, simple v complex) on driving performance (ie, speed control) was evaluated among adults with TBI and healthy controls.

METHOD

Subjects

The subjects consisted of three individuals with moderate to severe TBI and three age-, gender-, and education-matched healthy controls (HC). All subjects were right-handed men. Two of the individuals with TBI were currently driving at the time of testing; one individual had been driving for 18 years before his injury and 1 year after his injury; and the other individual had been driving for 3 years after his injury. The third individual with TBI had been driving for 13 years before his injury and was in the process of receiving a driving evaluation to reinstate his driver's license at the time of testing. None of the subjects required any type of adaptive equipment to assist with driving, and none

had any gross physical limitations that would affect their ability to drive a vehicle.

TBI subjects were recruited from a database of individuals who had previously participated in other research studies. The mean interval between onset of TBI and time of testing was 12.67 years (SD = 9.29; range, 5–23 years). The mean age of the TBI group was 38 years (SD = 3.46; range, 34–40 years), and the mean years of education was 13.3 years (SD = 1.53; range, 12–15 years).

HC subjects were recruited from hospital staff or individuals from the community who had previously participated in other research studies. The mean age of the HC group was 38 years (SD = 3.61; range, 34–41 years), and the mean years of education was 16 years (SD = 2.00; range, 14–18 years).

The TBI and HC groups were matched for age, education, and gender (all subjects were men). All subjects with a history of any neurological disease, drug or alcohol abuse, or significant psychiatric disorders were excluded from study participation.

Procedures

All subjects completed an institutional review board-approved consent form at the beginning of the testing session. Subjects completed the protocol in one testing session lasting approximately 2 to 3 hours. During this session, subjects completed neuropsychological measures, as well as two computerized measures, the Useful Field of View (UFOV)³⁵ and a Driving Divided Attention Task.

Neuropsychological measures

Subjects were administered the Auditory Consonant Trigrams³⁶ and the Paced Auditory Serial Addition Test (PASAT) to assess divided attention, working memory, and information processing.³⁷ Tests were administered according to standardized protocols.

A divided attention task, which involved performing two tasks concurrently, was administered. Various divided attention tasks (ie, dual tasks) have been reported in the literature and have included tasks such as card sorting with random item generation, backward counting with a cancellation task, digit recall with a cancellation task, a simple visual reaction time task with random number generation, and a visual reaction time task with counting aloud.³⁸⁻⁴¹ For this study a verbal fluency task and a cancellation task was chosen as the divided attention measure, because it had previously been used in the literature and involved a verbal and visual component. For the single (ie, non-dual task condition) verbal fluency task, the letter “F” was administered alone using standard administration instructions (ie, generate as many novel words in 60 seconds without repetitions or rule violations). For the single cancellation task, subjects were given 60 seconds to cancel out the number “9” alone. For the divided attention task, the verbal fluency and cancellation tasks were administered concurrently. The letter “L” was administered with the number “6” as the cancellation task. The letters “F” and “L” were chosen, because they have been shown in the literature to produce a similar number of words per minute.⁴² Likewise, the number 6 and 9 were chosen for the cancellation task as these have been reported to provide equivalent scores.⁴³

Useful field of view (UFOV)

The UFOV³⁵ is a standardized and commercially available product that quantifies the visual field area (useful field of view) over which a driver can process rapidly presented visual information. The UFOV is used to assess driving-related skills and is composed of three subtests: visual information processing, divided attention, and selective attention.



Fig 1. Sample road scene.

Driving divided attention task

The driving divided attention task consisted of a primary task (driving a VR route) and a secondary task (attending to numbers in the driver’s visual field). The driving divided attention task was delivered using a VR-Driving Simulator computer program based on the study by Levine and Mourant.⁴⁴ Specifically, all subjects sat in front of a PC computer with a 21-inch monitor screen equipped with a steering wheel and gas/brake pedals. The program consisted of a simple VR driving route that included a 1.75-mile long, two-directional roadway containing four curves. The driving lane was approximately 12 feet wide. See Figure 1 for a sample scene of the roadway.

Primary task: VR driving task

Subjects were required to “drive” the vehicle through the VR driving route, using the steering wheel and foot pedals and keeping in the center of the lane. Automatic recording of the subjects’ speed (mph) was logged through the computer every 100 milliseconds. Upon the completion of the route, an average speed was calculated and used as the dependent variable for driving performance.

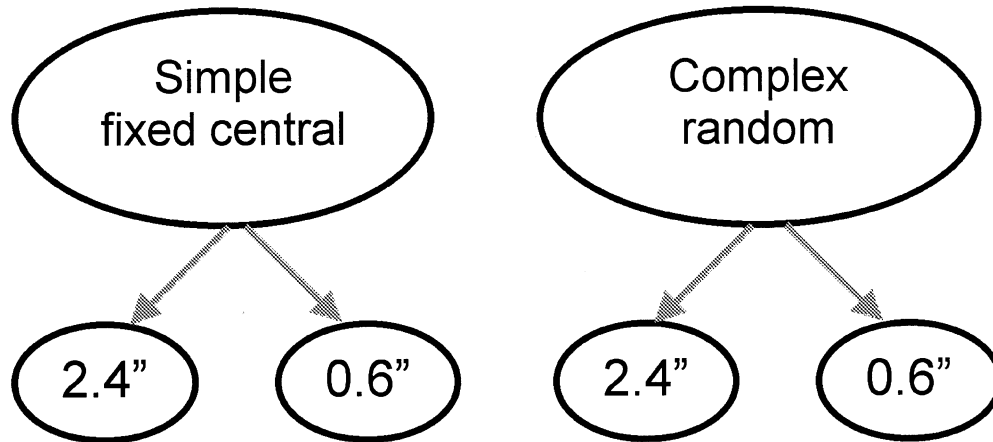


Fig 2. Study design.

Secondary task: Divided attention tasks

The secondary task involved the presentation of a four-digit number superimposed on the computer screen (“windshield”) while the subject drove the VR driving route. Each four-digit number was presented for approximately 300 ms and was randomly selected by the computer from a database of pre-screened numbers. Subjects were required to say the number out loud immediately after it appeared on the screen while they continued driving. A tape recorder was used to record responses.

The present design consisted of five driving divided attention conditions, a baseline condition, and four divided attention conditions (see Figure 2). The four divided attention conditions were counterbalanced to control for learning effects.

1. Baseline condition: The baseline condition consisted of having the subjects complete the primary task one time (ie, drive the VR driving route) without the presence of the secondary task (ie, numbers were not presented).
2. Divided attention conditions: These conditions required subjects to drive the VR driving route while attending to the sec-

ondary task (described previously). The four divided attention conditions were:

- Simple 2.4” condition: In this condition, the four-digit number always appeared in a fixed central location on the “windshield.” The numbers were presented at 2.4” intervals.
- Simple 0.6” condition: The procedure for this condition was identical to the simple condition described previously except that the numbers were presented at 0.6” intervals.
- Complex 2.4” condition: The procedure for this condition was similar to the simple condition with the exception that the numbers appeared randomly throughout the “windshield” rather than in one fixed central location. The numbers were presented at 2.4” intervals.
- Complex 0.6” condition: The procedure for this condition was similar to the preceding complex condition except that the numbers were presented at 0.6” intervals.

For each of these conditions the total number of errors in recalling the four-digit number was recorded for each subject. Because

total numbers presented varied between subjects (because of difference in speed and time taken to complete the driving route), an overall error percentage was calculated and used as the dependent variable for the driving divided attention task.

Data analysis

The small sample size and preliminary nature of this investigation precluded a parametric analysis of the data. Therefore, emphasis was placed on descriptive analyses. After consultation with a statistician, nonparametric statistics were used to assess any trends in performance for both speed and errors. Data on driving speed and percentage of errors on the driving divided attention task were exam-

ined. The Mann-Whitney test was used to examine preliminary differences in speed and errors between the TBI and HC group. Finally, Spearman's correlations tests were used to examine the relationship between standardized neuropsychological tests of divided attention and the driving divided attention task.

RESULTS

Driving divided attention task

Driving speed

The average speeds for both the TBI and HC groups on the baseline for each of the four divided attention conditions are depicted in Figure 3. To examine differences in speed on

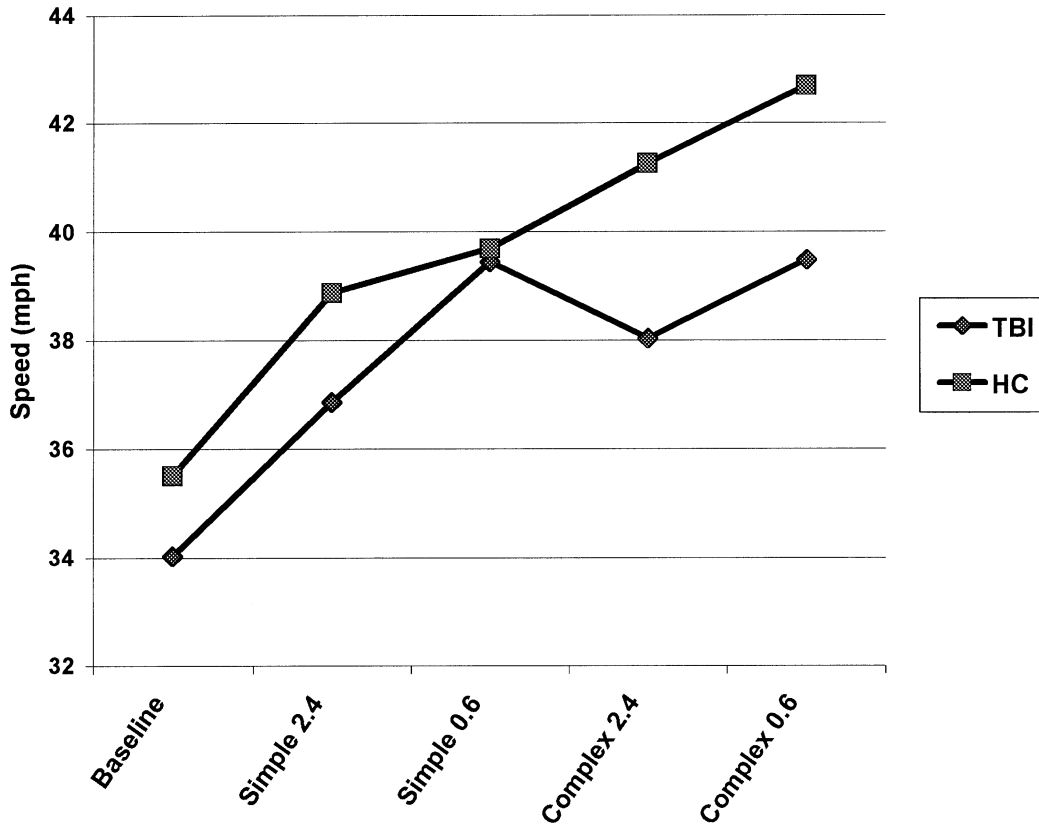


Fig 3. Average speed on driving task.

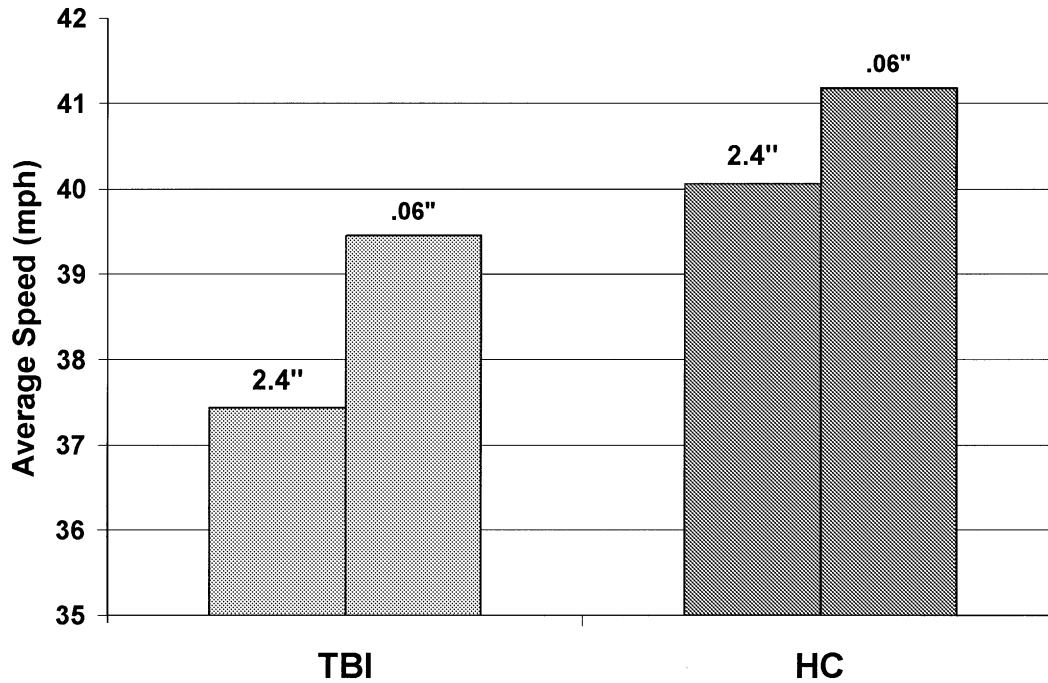


Fig 4. Speed and presentation rate of stimuli.

the driving divided attention task between the TBI subjects and HC, a difference score for each subject was computed based on their baseline speed and speed on each of the four divided attention task conditions (simple 2.4'', simple 0.6'', complex 2.4'', and complex 0.6''). Preliminary findings did not indicate any differences in relative speed between the TBI and HC on any of the four divided attention conditions. In addition, TBI and HC did not seem to differ when the secondary task was either simple (ie, presented in a central fixed location) or complex (ie, presented in random locations).

In examining the data from the driving divided attention task, some preliminary trends in speed performance could be identified. First, it was observed that speed increases for both groups when the secondary task (ie, divided attention task) is added to driving. That is, compared with the speed observed

during the baseline condition, five of the six subjects increased their speed during the divided attention conditions (see Figure 3). This suggests that the complexity of visual attention (simple v complex) required for the secondary task may not have an impact on driving speed. In addition, subjects in both the TBI and HC group seemed to increase their speed when stimuli were presented at 0.6'' compared with 2.4'' (see Figure 4). These data may suggest that how quickly one must attend to stimuli may have an impact on their driving speed, for both TBI and HC subjects.

Errors

The percentage of errors for both the TBI and HC group on each of the four divided attention conditions are depicted in Figure 5. The percentage of errors made across subjects was examined for each of the four divided

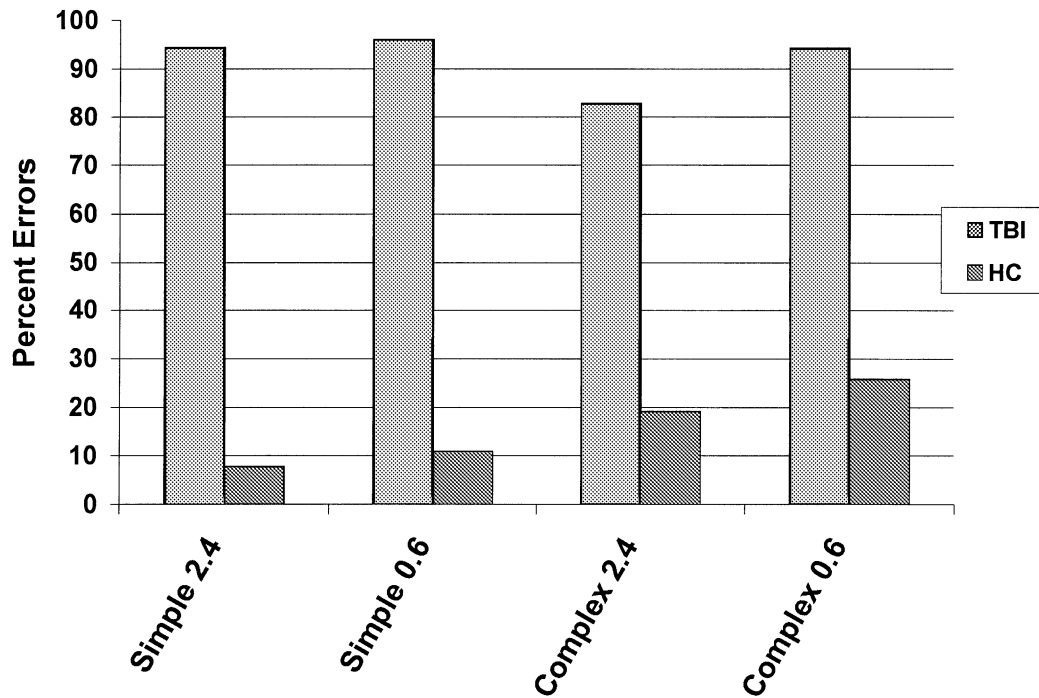


Fig 5. Percentage errors on number recognition task.

attention conditions (simple 2.4", simple 0.6", complex 2.4", and complex 0.6").

In examining the data from the driving divided attention task, some preliminary trends in error performance can be identified. No group differences in errors were observed between whether stimuli were presented in a fixed location (ie, simple) or random locations (ie, complex). This suggests that the complexity of visual attention (simple v complex) required for a secondary task does not affect error rate. However, it seems that the rate at which stimuli are presented (ie, 0.6" or 2.4") affects error rate. In the simple condition, both the TBI and HC subjects committed a greater number of errors when stimuli was presented at 0.6" compared with 2.4". A similar pattern was evidenced in the complex condition. This suggests that how quickly one must attend to stimuli may have an impact on

the ability to perform a divided attention task correctly in both TBI and HC subjects. This is similar to the pattern observed in the driving performance measure.

Neuropsychological measures

Neuropsychological divided attention task

Performance on the fluency and cancellation divided attention task was examined between the TBI and HC groups. A difference score between the number of words generated when the fluency task was done alone (single task) and number of words generated concurrently with another task (divided attention task) was computed for each subject. Preliminary analysis did not indicate any differences in the number of words generated on the single fluency task compared

Table 1. Average speed (mph) on driving divided attention task

Subject	Baseline	Simple 2.4"	Simple 0.6"	Complex 2.4"	Complex 0.6"
TBI #1	45.62	49.31	50.55	50.30	53.16
TBI #2	29.72	35.34	39.32	35.01	39.09
TBI #3	26.76	25.94	28.44	28.78	26.18
HC #1	38.81	49.97	49.13	47.43	54.18
HC #2	36.29	38.24	39.76	44.02	37.22
HC #3	31.43	28.37	30.14	32.33	36.67

with fluency during the divided attention task for either the TBI ($t = -.143$; $p = .89$) or HC groups ($t = 1.95$; $p = .19$). A difference score was also computed for the number of correct responses on the cancellation task when it was performed alone (single task) and concurrently with the fluency task (divided attention task). In contrast to the fluency data, cancellation task performance during the divided attention task was significantly reduced compared with the single task condition for both the TBI ($t = -4.42$; $p < .05$) and HC groups ($t = -8.32$; $p < .05$). These results suggest that during the divided attention task, performance on a secondary task decreases (ie, cancellation) as attention is allocated to the primary task (ie, fluency).

Driving divided attention task and neuropsychological measures

Given the preliminary nature of the study, it was important to examine the relationship between the VR driving divided attention task and more traditional measures of divided attention. To address this, correlational analysis comparing the driving divided attention task and standard neuropsychological measures of divided attention was conducted. Given the small sample size, the data must be viewed as preliminary.

Correlations between the divided attention subtest of the UFOV, total number of correct responses on the PASAT, and total number cor-

rect on Consonant Trigrams with two measures from the driving divided attention task, driving speed and errors, were analyzed. With respect to driving speed, minimal to no correlations were initially present (UFOV, $r = 0.08$; $p = .93$; PASAT, $r = -0.02$; $p = 1.0$; Consonant Trigrams, $r = -0.20$; $p = .72$). In comparison, higher correlations were seen when comparing errors on the driving divided attention task with neuropsychological measures of divided attention. Errors were correlated with divided attention subtest of the UFOV ($r = 0.79$; $p = .10$), indicating that the greater the number of errors on the driving divided attention task, the longer the reaction time on the UFOV divided attention subtest. Errors were also correlated with the PASAT ($r = -.94$; $p = .01$), indicating the more errors on the driving divided attention task, the lower total number of correct responses on the PASAT. Errors were not found to be highly correlated with the total number correct on Consonant Trigrams ($r = -.40$; $p = .44$).

DISCUSSION

The purpose of this pilot study was to begin to examine the potential benefits offered through VR to more closely investigate the relationship between divided attention and driving performance. The findings suggest that VR may provide a

unique medium for direct evaluation of basic cognitive functions (ie, divided attention) and its impact on everyday tasks (ie, driving) not previously available through traditional neuropsychological measures.

Specifically, preliminary results from this pilot study suggest that when drivers are required to attend to multiple elements of information, there are increased errors on the secondary task (ie, number recall), whereas performance on the primary task (ie, driving) is less impacted. For this study, the results suggest that drivers with TBI demonstrated more errors on the secondary task compared with HC drivers. This finding is consistent with prior studies examining secondary tasks during driving.^{14,45} The present findings also suggest that when drivers must divide their attention to more than one task, speed of driving seems to increase for both TBI and HC drivers. Interestingly, initial results indicate that the type of divided attention (ie, simple v complex task) did not seem to have the most impact on speed of driving, but rather, the speed of stimulus presentation (ie, 2.4 s v 6 s) seemed to influence performance.

Although previous work has reported a relationship between divided attention and driving, prior results are based on correlation analysis and used correlational comparisons between psychometric test results and behind-the-wheel driving observations rather than direct examination of driving behaviors. As such, the specific aspects of how driving is affected (ie, speed increase, lane de-

viation) has not been delineated. This pilot study illustrates how VR can be used to address this limitation in prior studies and allow for an objective and direct evaluation of the relationship between cognitive impairment (ie, divided attention) and functional performance (ie, driving). By use of a VR approach, the levels of divided attention tasks can be manipulated, and actual driving measures such as speed and lane position can be recorded. This type of evaluation may have implications for the assessment and rehabilitation of driving skills for cognitively impaired populations.

Although promising, the initial findings of this pilot study must be viewed as preliminary and must await extension and replication. The limitations of this study to date include subjects not matched for driving experience. In addition, the small sample size of this pilot study requires nonparametric statistics and cautious interpretation of trends in performance. Our continued work is focusing on obtaining larger samples, addressing questions of validity and reliability, and comparing the VR divided attention task to traditional neuropsychological and driving measures.

Because the application of VR to neuropsychology is in early stages, future studies can provide information about the use of VR to extend and enrich our neuropsychological assessments. VR seems to offer an innovative and promising mechanism that can be used for objective and direct evaluation of the relationship between cognitive impairment and functional performance.

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