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Jun 30th, 12:00 AM

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Thompson, Kelsey; Read, Katherine; Anderson, Steven; and Rizzo, Matthew. Systematic Analysis of Real-World Driving Behavior Following Focal Brain Lesions. In: Proceedings of the Sixth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, June 27-30, 2011, Olympic Valley — Lake Tahoe, California. Iowa City, IA: Public Policy Center, University of Iowa, 2011: 576-582. <https://doi.org/10.17077/drivingassessment.1449>

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## **SYSTEMATIC ANALYSIS OF REAL-WORLD DRIVING BEHAVIOR FOLLOWING FOCAL BRAIN LESIONS**

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**Summary:** Many patients with circumscribed brain injuries, such as those caused by stroke or focal trauma, return to driving after a period of acute recovery. These persons often have chronic residual cognitive deficits that may impact on driving safety, but little is known about their driving behavior in the real world. Extant studies tend to rely on driving simulators or controlled on-road drives. These methods of observation are not able to capture the complexities of the typical driving environment, and may not accurately represent a driver's usual behavior on the road. The current study used a video event-activated data recorder (VEADR) system to observe drivers with focal brain lesions in their normal daily driving environment over a three-month period. In the context of primarily safe driving behavior, we were able to document a number of relatively infrequent and hitherto unobserved high risk behaviors and traffic violations. These findings demonstrate the feasibility and value of sampling real-world driving in neurologic patient populations such as those with focal brain lesions, and highlight the critical importance of evaluating unsafe driving behaviors which may occur with insufficient frequency to be captured by relatively brief simulator or controlled on-road evaluations.

### **INTRODUCTION**

Driving is a complex task that places demands on multiple neurocognitive systems. In addition to the attentional, perceptual and motor demands, drivers must monitor and evaluate multiple external factors, such as tracking the location of surrounding vehicles, judging when it is safe to pass a slower vehicle, and obeying traffic signals and signs (Trick, Enns, Mills, & Vavrik, 2004). Driving clearly places major demands on executive functions such as attentional control, decision making, planning, and execution of actions. Acquired impairment in these functions due to brain injury or disease can have a detrimental impact on driving (Anstey, Wood, Lord, & Walker, 2005; Lundqvist et al., 1997; Marcotte et al., 2004; Rizzo et al., 2004). Drivers with executive dysfunction may also have difficulty formulating and executing necessary actions based on current driving conditions (e.g., traffic density, surrounding vehicle positions, traffic signals/signs; Uc & Rizzo, 2008).

Many studies have examined the effects of executive dysfunction on driving, such as in persons with Alzheimer's disease (Grace et al., 2005; Uc & Rizzo, 2008), Parkinson's disease (Grace et al., 2005; Uc & Rizzo, 2008; Uc et al., 2007), or Obstructive Sleep Apnea Syndrome (Verstraeten, 2007). These studies found that deficiencies in executive functioning predicted impaired driving. While these studies support the link between executive dysfunction and poor driving performance, they are also methodologically limited. For example, these studies have

assessed driving performance during brief on-road tests in instrumented vehicles (IV) or in driving simulators. Simulator-based driving assessments are limited in reproducing the complex and varied conditions of real roads and alter the decision-making environment of participants, encouraging them to make riskier choices than in their own cars on the road (Horrey & Wickens, 2006; Rizzo et al., 2004). In contrast, IV-based driving assessments under the supervision of a trained researcher may induce the opposite behavior. Drivers may be inclined to drive more cautiously than they normally would, conscious that they are being observed and are not driving their own vehicle. In addition, assessments are often conducted in optimal weather and traffic conditions to minimize risks to participants (Dawson, Anderson, Uc, Dastrup, & Rizzo, 2009). These methodological limitations constrain the usefulness and accuracy of driver fitness measures obtained from simulator- and IV-based assessments, and findings based on those methods are likely to lead to biased conclusions on correlates and predictors of driver fitness.

With technological advances, however, it is now possible to conduct naturalistic assessments of driver fitness while people drive their own cars during the course of everyday activities. To date, only a few large-scale naturalistic driving studies have been conducted, including the 100-Car Naturalistic Driving Study conducted by the Virginia Tech Transportation Institute. These studies have captured video images and on-board data including various kinematic measures, headway detection, side obstacle detection, and lane-keeping. This approach to monitoring daily driving habits has allowed for a more realistic view of driver behavior over the course of time in real-world situations (Hanowski, et al., 2000; Neale, Dingus, Klauer, Sudweeks, & Goodman, 2006; Stutts et al. 2003). Naturalistic assessments of driver performance is an essential direction for current and future research that will overcome many of the methodological weaknesses associated with simulator and IV-based assessments of driver fitness.

The few studies that have relied on naturalistic assessments of driving were conducted with neurologically normal participants. The current pilot study investigated the feasibility of using a VEADR system to collect information on naturalistic driving behavior in persons with focal brain lesions and residual cognitive impairments. We aim to gather observations of naturalistic driving behaviors in order to identify factors that contribute to driver safety and characterize mobility patterns among persons with neurologic injury or disease.

## **METHOD**

### **Participants**

Participants were six currently licensed drivers aged 49 to 83 years with focal brain lesions, recruited from a study currently being conducted by our research team on driving in advancing age or from the registry of persons with focal brain lesions maintained in the project "Anatomical Substrates of Complex Behavior" at the University of Iowa Department of Neurology. Potential participants were excluded if they had any confounding medical conditions such as dementia, major psychiatric disease, vestibular disorders, or substance abuse. Use of prescription medications was allowed with the exception of stimulants, antihistamines, narcotics, anxiolytics, anticonvulsants, and neuroleptics. Participants were not excluded because of visual defects unless they had corrected visual acuity worse than 20/50. Informed consent was obtained in accordance with the guidelines of the Institutional Review Board of the University of Iowa.

## Design and Procedure

The VEADR instrumentation package, (DriveCam, San Diego; plus GPS) was installed in the participants' primary vehicle for a period of 90 days in four drivers. One participant drove for only 30 days with the data collection equipment installed, and one participant drove for two and a half months. The VEADR package was installed so as to minimally interfere with the participants' driving ability, and participants were instructed to drive as they normally would.

The DriveCam is approximately the size of a deck of playing cards, mounted behind the rear-view mirror. The system is triggered during ignition starts, abrupt steering and braking maneuvers made by the driver (greater than 0.3 g-force) and at set intervals. When triggered, the system captures 12 seconds of audio and video from the forward view and of the driver and vehicle interior. The GPS tracker is a small device plugged into the vehicle's on-board diagnostic (OBD) system to record speed and position data at set intervals.

*Coding.* Each triggered event video was reviewed based on a coding scheme developed by Carney, McGehee, Lee, Reyes, and Raby (2010). In addition to categorizing basic elements such as weather and road type/condition, videos were coded for two broad categories of events: driver behaviors (Table 1) and vehicle control (Table 2). Each category contained several specific outcomes, with the possibility of coding multiple outcomes in a single video.

## RESULTS

This system allowed us to characterize each patient's pattern of driving mobility, including time spent in vehicle, miles traveled, geographic distance covered, patterns of repetitive route following, and driving environment (urban v. rural, road type and speed zones). Fewer than 10% of triggered and randomly timed observations represented unsafe driving or traffic violations. However, in the context of primarily safe and normal driving behavior, the VEADR system captured numerous instances of unsafe driving. Key driving behavior and vehicle control events observed over approximately 450 driving days are presented in Tables 1 and 2. The monitoring system was able to capture several types of in-vehicle safety-relevant behaviors, including cell phone use, grooming behavior, and distraction by pets, food, or loud music. In addition, safety-critical vehicle maneuvers were captured, including running red lights and stop signs, going the wrong way on one-way streets, and crossing the center line. Several brief driving profiles are presented below to illustrate the manner in which this observation and coding system can characterize individual patients' real-world driving behaviors.

**Table 1. Examples of Driver Behavior**

Driver Behavior	Description	Count
Reckless driving	Risky, intentional behavior by the driver; don't appear to be concerned about the consequences of their driving; assertive, forcing others to respond to their actions; taking hands off wheel	7
Driving while fatigued	Yawning; blank /fixed staring; rubbing eyes; slack facial muscles	49
Distracted driving		
Music distraction	Too loud	399
Cognitive distraction	Looked but did not see; talking/singing	123
Object / Animal distraction	Pet in vehicle; reaching for object	42
Cell phone distraction	Talking/listening on phone; dialing phone; reaching for/answering phone; texting	42
In-vehicle distraction	Adjusting radio or other devices	34
Eating / smoking	Eating or drinking while driving; lighting/smoking cigarette	6
Personal hygiene	Brushing hair; brushing teeth; removing/adjusting jewelry; applying makeup	19
Inattention to the road	Looking in mirrors (side/rearview), out window; or down inside the vehicle	43

**Table 2. Description of the various vehicle control outcomes observed during event triggers**

Vehicle Control	Description	Count
Running a red light	Entering the intersection after light has turned red; failing to stop before right turn on red	17
Running a stop sign	No reduction in speed before sign; failing to come to a complete stop (i.e., rolling through intersection)	93
Excessive speed on straight-aways	Exceeding the speed limit	1
Improper turns	Accelerating through turn; cutting the corner; turning too fast; wide turns; turning from wrong lane	1545
Crossing lane boundaries	Turning down a one-way street; drifting across center line; drifting onto shoulder	18
Avoiding maneuvers	Avoiding another vehicle, pedestrian, or object in the road	156

Participant 200, a 70 year old male, suffered a right insula/basal ganglia stroke in 1995. On two instances, the subject was seen responding positively to a situation in which another vehicle entered his path. In both cases, the subject had to respond quickly to avoid the other car. The subject was also recorded showing inattentiveness during driving on two occasions. During one event, he attempted to grab an object out of view of the camera, though he appeared to be in complete control of the car. However, during another instance of inattentiveness the subject was waving and looking out the side window during a right turn. He swung wide while turning and had to quickly correct in order to avoid running into an approaching car head-on.

Participant 201 is a 73 year old male who suffered at left parietal stroke in 2000. Over the course of three months, the subject failed to come to a complete stop at a stop sign on 8 occasions. These events were not overt inattention to the stop sign, but were instances where the driver approached the intersection and rolled through the stop sign at less than 5 mph. In general, these events were captured by the system's low trigger setting (0.3 g), picking up abrupt braking, acceleration, or hard steering maneuvers, and did not represent reckless driving.

Participant 202, a 75 year old female who suffered a bilateral frontal stroke in 2001, routinely failed to come to a complete stop at a stop sign near her home, accounting for the majority of this type of event across all subjects. On 9 occasions, the participant either rolled through a stop sign, similar to the previous subject, or failed to stop completely when making a right turn on a red stoplight. Like subject 201, the instances only occurred when no other car was preceding through the intersection.

Participant 203 (83 year old female; left basal ganglia stroke in 2002) also did not come to a complete stop at stop signs. On 14 occasions in the three-month period, the subject rolled through stop signs at a relatively slow speed (< 5mph). She was also witnessed running two red lights. On both occasions, she entered the intersection just after the light turned red. She did not appear to be aggressive and did not engage in any distracting behaviors.

Participant 204 (57 year old female; left frontal stroke in 2000) had six instances of driving the wrong way down the road. All such instances occurred along the same roadway, which transitioned from an undivided to divided street. The driver repeatedly chose to drive a short distance down the wrong side of the boulevard in order to turn into a parking lot, rather than driving until she reached a point where she could cross the division. Like the above participants, she often failed to come to a complete stop at stop signs, rolling through at 4-5 mph. She also ran four red lights over 90 days of driving, three on left turns (just as the light turned red) and once on a right turn (similar to participant 200/202). In addition, she was captured having cell phone conversations 33 times and three times looking away from the road to dial her phone three times.

Finally, participant 206 (49 year old male; right frontal trauma in 2008) commonly drove late at night and/or with loud music on. GPS data also indicated a repeated pattern of late-night stops in the vicinity of taverns. In general, this driver had a more aggressive style compared to the other participants, and we consequently recorded nearly three times as many triggered events from his vehicle. Over the three month period, the VEADR captured four instances where he ran a red light. He also commonly rolled through stop signs and tended to take turns at high speeds. In addition, he engaged in several interesting driver behaviors, such as talking on a cell phone, brushing his teeth, and eating while driving.

## **DISCUSSION**

These findings indicate that naturalistic studies of the driving behaviors and vehicle control patterns of patients with chronic neurologic disease can provide an important source of information regarding safety risk and large-scale mobility of these individuals. Such studies are an important addition to driving simulation and controlled-route drives in instrumented vehicles for these patients. The behaviors we observed in this naturalistic driving assessment captured the diversity and complexity of actual driving situations, as well as many safety-critical but relatively infrequent events that are often not seen in simulator and/or IV-based assessments.

Typically, data collection in the lab lasts for an hour or less, greatly reducing the likelihood that a crash or major traffic violation will occur during this time. Instead, researchers rely on self-report questionnaires to obtain information on driving behaviors of at-risk drivers. However, self-report data is often inaccurate, especially considering that subjects may have memory or cognitive

deficits. Crash data, vehicle usage information and driver strategy are more likely to be captured in a naturalistic setting rather than during a controlled laboratory drive (Rizzo, Robinson, & Neale, 2007). Furthermore, the future of naturalistic observation of drivers could allow for a more individualized approach to evaluating and modifying driving behaviors following brain injury or disease. Targeting a driver's strengths and weaknesses over time in a naturalistic setting can allow researchers to curb potentially dangerous behaviors that might not emerge in a shorter controlled drive within the lab.

While we did not observe any crashes or near-crashes in the current study, the instrumentation package employed in this study proved to be practical and reliable, and it elicited few complaints from participants. A major concern in sampling driving over an extended time frame as in the current study is how best to set the triggers to capture important events while not generating impractical amounts of data reflecting only normal behavior. The majority of the events we observed at lower levels (e.g., 0.3-0.35) reflected hard braking or turning, but nothing that would suggest reckless or unsafe driving. However, some of the illegal maneuvers captured by the VEADR, such as running a red light, occurred at lower g-force triggers. Supplementing g-force triggers with random sampling helps address this issue, but it remains likely that we missed many low g-force safety-relevant events. GPS-guided geocentric triggers may provide a more efficacious supplement to measuring safety relevant events in future studies.

## ACKNOWLEDGEMENT

This study was supported by awards AG 17717 and AG 15071 from the National Institute on Aging (NIA).

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