COLLISION AVOIDANCE TRAINING USING A DRIVING SIMULATOR IN DRIVERS WITH PARKINSON'S DISEASE: A PILOT STUDY

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Summary: Parkinson's disease (PD) impairs driving performance, and simulator studies have shown increased crashes compared to controls. In this pilot study, eight drivers with PD participated in three drive sessions with multiple simulator intersections of varying visibility and traffic load, where an incurring vehicle posed a crash risk. Over the course of the three sessions (once every 1-2 weeks), we observed reduction in crashes (p=0.059) and reaction times (p=0.006) to the vehicle incursion. These findings suggest that our simulator training program is feasible and potentially useful in drivers with PD. Future research questions include transfer of training to different driving tasks, duration of benefit, and the effect on long term real life outcomes in comparison to a standard intervention (e.g., driver education class) in a randomized trial.

INTRODUCTION

PD impairs motor function, cognition, vision, and alertness [Uc *et al.*, 2005]. Drivers with PD have performed worse on various driving tasks and made more safety errors compared to drivers of similar age without neurological disease.[Heikkila *et al.*, 1998; Wood *et al.*, 2005; Worringham *et al.*, 2006; Amick *et al.*, 2007; Devos *et al.*, 2007; Uc *et al.*, 2007a; Uc *et al.*, 2006b; Uc *et al.*, 2006c]. Driving simulator experiments showed that drivers with PD had poorer vehicle control [Madeley *et al.*, 1990; Moller *et al.*, 2002; Stolwyk *et al.*, 2005; Stolwyk *et al.*, 2006] and increased risk of crashes [Zesiewicz *et al.*, 2002; Uc *et al.*, 2007b]. However, there is no standard and proven driver rehabilitation program for drivers with PD.

Roadway intersections pose special safety challenges to drivers with cognitive, visual, and motor impairments due to high information processing demands needed for rapid reactions such as in response to sudden moves by other vehicles [Rizzo *et al.*, 2001]. We studied crash risk of drivers with PD (67 drivers with PD and 51 control drivers) using a simulated intersection incursion scenario under low visibility conditions [Uc *et al.*, 2007b]. A driver's approach to within 4.0 seconds of an intersection triggered an illegal incursion by another vehicle posing crash risk. A larger proportion of drivers with PD crashed compared to controls (76.1% vs. 37.3 %, p<0.001). The time to first reaction (TFR, e.g., releasing accelerator, braking, or steering away) of drivers with PD was slower than that of controls (median 2.7 vs. 2.1 seconds, $p<0.001$) [Uc *et al.*, 2007b].

To improve the driving safety at intersections in driver with PD, we developed a pilot training program based on multiple simulator drives. There were three identical drives with multiple intersections of varying crash risk, administered once every 1-2 weeks. Using this repetitive exposure to intersections, we intended to enhance the procedural memory of drivers with PD, which could lead to faster and safer behavior at intersections.

We hypothesized that this training program with repetitive exposure to intersection challenges will improve the reaction times and crash rates within the same task and platform in drivers with PD. The emphasis of this study was to address feasibility and proof of concept, with the hope that future studies could investigate transfer of the potential benefits to other tasks and real life outcomes, or comparison to other interventions. Therefore, no control intervention or other outcome measures beyond the simulator platform were used.

METHODS

Subjects. The drivers with PD (age=64.6±5.8, 8 men, Hoehn-Yahr stage II-III) were recruited from the Movement Disorders Clinics at the Department of Neurology, University of Iowa and Veterans Affairs Medical Center, both in Iowa City. The participants represented a convenience sample from a PD cohort who participated in a driving study in the recent past. All subjects had mild to moderate PD severity (Hoehn-Yahr stage II-III) and were independently living and licensed active drivers. We performed all testing during the "on" times (optimal effect of antiparkinsonian medications) when the subject would normally feel ready to drive.

Driving Simulator. Our driving simulator known as SIREN [Uc *et al.*, 2006a; Rizzo *et al.*, 2002] comprises a 1994 GM Saturn, embedded electronic sensors, miniature video cameras for recording driver performance, a sound system and surrounding screens (150º forward FOV, 50º rear FOV), four LCD projectors with image generators, an integrated host computer, and another computer for scenario design, control, and data collection. A tile-based scenario development tool (DriveSafety, Salt Lake City, UT) was used.

Simulator Training: The training drive (Table 1) sessions were administered in 1-2 week intervals.

All participants were familiar with driving simulation in SIREN from their participation in a recent driving study. In each training session the driver passed through 20 intersections on a simulated two-lane highway, one mile apart, from each other, with waiting vehicles positioned in one crossing lane and in the opposing lane. The driver was advised to drive close to the speed limit and a honking sound reminds the driver to pick up speed if it falls below 50 mph (except within 10 seconds of an intersection). Some of these intersections were "inactive" without any incursion occurring. In "active" intersections, the vehicle on the right pulled out in front of the driver, triggered in response to driver speed by a predetermined time-to-intersection (TTI). This event required immediate decision making and action by the subject to attempt to avert a crash. Optimal response involved releasing the accelerator, applying the brake, and making steering corrections as needed to remain within the lane. There was no systematic subject feedback after the drives.

Table 1. The characteristics of the intersections on the training drive

Intersection #	Incursion	Visibility	TTI trigger	Oncoming traffic
1	Y	D	4.5	Y
2	N	D	-	N
3	N	D	-	Y
4	Y	D	4.2	Y
5	N	D	-	N
6	Y	D	4.0	N
7	Y	D	3.6	N
8	N	F	-	N
9	Y	F	5.0	Y
10	Y	F	4.8	N
11	N	F	-	Y
12	Y	F	4.5	Y
13	N	F	-	N
14	Y	F	4.2	N
15	N	F	-	N
16	N	F	-	Y
17	Y	F	4.0	N
18	N	F	-	N
19	Y	F	4.0	Y
20	Y	F	3.6	N

TTI=Time to intersection (sec), Y=Yes, N=No, D=Daylight, F=Fog

Initially, the driver approached an intersection with long TTI trigger (e.g., 4.5 seconds) during daylight (good visibility). The level of difficulty of the intersection was increased gradually by shortening the TTI trigger (the longer the TTI, the easier to avoid collision), adding oncoming traffic to the opposite lane, and changing the visibility (daylight vs. fog) as shown in Table 1. Our choice of minimum TTI was guided by our prior findings that most normal drivers could avoid a crash in similar scenarios in daylight settings at a TTI of 3.6 sec [Rizzo *et al*., 2001] and in similar fog settings at a TTI of 4.0 sec [Uc *et al.*, 2007b]. However, at a TTI of 4.0 sec, the majority of drivers with PD (76%) crashed in fog settings [Uc *et al.*, 2007b].

Statistical Methods

At each intersection with an incurring vehicle, we noted whether a crash occurred, and we used the digitized data to measure the elapsed time (Time to First Reaction-TFR) between the beginning of the movement of the incurring vehicle into the intersection and the driver's first reaction. The moment of the first reaction was defined as the first frame when one of the following occurred: 1) The steering wheel was turned more than 10 degrees from centered position, 2) The accelerator pedal position dropping below 30% employment when being at least

30% employed at the previous frame, or 3) The brake pedal was employed more than 5% after having been employed less than 5% at the previous frame.

Means, standard deviations, and percentages were calculated as descriptive statistics. Risk factors for crashes and failures to react were identified using a logistic regression model which accommodated the random effects of the drivers, based on the Generalized Estimating Equation (GEE) method. The TFR was analyzed using mixed effects models. Since the TFR distribution was highly skewed, formal significance tests were performed on the natural log scale. However, for descriptive purposes, estimate effects and approximate confidence intervals are reported in the original scale (in seconds).

The primary risk factor of interest was the visit number (1, 2, and 3). Preliminary analyses showed no significant quadratic effects of visit, so a linear effect was used in the models. To ascertain whether the intersections presented the intended level of challenge, we also tested whether the outcomes were affected by the presence/absence of "fog" in the segment surrounding an intersection, the presence/absence of an oncoming vehicle, and the estimated time-to-impact (TTI) as predicted by the distance to the intersection and the velocity of the driver's vehicle at the time of the incurring vehicle's first movement. We also adjusted for the cumulative distance traveled when appropriate, to account for possible driver fatigue over the course of an individual drive. All analyses were performed in Stata version 9.2 (StataCorp LP, College Station, TX, 2007).

RESULTS

Each of the eight drivers was invited to perform in the simulator during three separate visits. We obtained data on a total of 20 drives (an average of 2.5 visits/driver). One driver dropped out of the study after the first visit due to simulator sickness. The data from the first visits of the first two subjects were not available due to technical problems. Since each drive contained 11 intersections with an incurring vehicle, this gave us 220 total intersections where we could ascertain performance.

The training drives were able to deliver the intended challenges at intersections. Lower visibility (fog) increased the mean TFR by 2.5 seconds (95% CI=1.0, 4.4; $p=0.002$) and was associated with more crashes. Of the total of 9 crashes in the 220 intersections (4.1%), all 9 crashes occurred in the fog ($P<0.001$). The presence of oncoming traffic improved the reaction time in drivers with PD by 0.48 seconds (95% CI=0.13, 0.83; $p=0.001$). However, 8 of 9 crashes occurred in the presence of an oncoming vehicle ($P=0.077$). The effect of the various factors (visibility, ambient traffic, TTI, cumulative distance traveled) on reaction time, were modeled simultaneously.

The TFR (mean±SD=1.40±1.06 seconds across all visits and intersections) improved with each successive visit by 0.21 seconds (95% CI=0.03-0.39), $p=0.006$, adjusted for visibility, ambient traffic, TTI, cumulative distance traveled. Furthermore, the number of crashes decreased with each successive visit (4, 3, and 2, respectively; $P=0.059$).

DISCUSSION

A pilot simulator training program, using repeated simulated drives across intersections of increasing difficulty, led to decreased crash rates and better TFR across training sessions in drivers with PD, even after adjusting for visibility, level of ambient traffic, TTI, and intersection sequence, suggesting usefulness of the program for different intersection settings.

Our pilot training protocol was designed to address deficits in visual perception, cognition, and motor function identified in drivers with PD [Uc *et al.*, 2005] and associated with poor outcomes in a crash scenario similar to the training task [Uc *et al.*, 2007b]. Our simulator procedures can be considered as a kind of cognitive training program aimed at improving the procedural memory and motor plans to navigate through intersections by means of repeated exposure. Our pilot results are consistent with possibility of improvement using cognitive training programs on other aspects of PD such as automatic performance of learned movements [Wu and Hallett 2005] or a executive functions [Sammer *et al.*, 2006]. Although PD is a progressive neurodegenerative disorder, patients survive for 15-20 years after diagnosis and usually drive within the first decade of their illness [Uc *et al.*, 2007a; Uc *et al.*, 2006b; Uc *et al.*, 2006c]. This relatively long driving period during PD may allow driver training programs in PD to be potentially useful in improving driving safety during the first decade of the disease or in prolonging the preservation of mobility.

We note that patterns of performance of our drivers with PD in response to our pilot training scenarios provides a source of evidence on the external validity of the design of our scenarios in terms of representing the intended driver challenges. Consistent with the visual perception and cognition impairments in PD, decreased visibility and increased ambient traffic load at the intersections were associated with increased crashes. Lower visibility (fog) was also associated with increased TFR. Conversely, the presence of oncoming traffic improved the TFR in drivers with PD, consistent with reports that attentional performance in PD improves in response to external cues [Uc *et al.*, 2006c; Stolwyk *et al.*, 2005a]. The TFR and crash rates improved across visits even after adjusting for visibility, level of ambient traffic, TTI, and cumulative distance traveled, suggesting usefulness of the program for different intersection settings.

The potential of simulator training in elderly with neurological disorders has been shown by other researchers. In one study [Akinwuntan *et al.*, 2005], patients with recent stroke received feedback on their performance after a 13.5 km course in a simulator. This baseline assessment was followed by a 5 week training program in the simulator, using a variety of different 5-km training scenarios that evaluated lane tracking, speed control, overtaking, road sign recognition, and response to differing traffic hazards. A post-training assessment (that changed the scenario sequence in the original 13.5 km course) showed significant improvements in number of collisions, pedestrians hit, faults, and run-time compared to the pre-training baseline. Stroke patients who were randomized to simulator training were more likely to pass an official driving assessment compared to those trained in driving-related cognitive tasks (73% vs. 42%) [Akinwuntan *et al.*, 2005]. In a related study [Akinwuntan *et al.*, 2007], performance in divided attention tasks was measured before, during, and after simulator-based training. There were significant improvements in mean response time (but not in the correct responses) to the divided attention tasks and time to complete the 5-km scenario, mainly observed in the first half of the training period. Similar, to Akinwuntan et al. (2005, 2007), our drivers also drove interactive driving scenarios in repeated sessions, with collection of performance measures during the drives.

The results of this pilot study motivate further research on the extent to which the gains observed within the task in our pilot driving simulation training study may transfer to benefits in analogous driving situations in the simulator (e.g., [Akinwuntan *et al.*, 2005; Akinwuntan *et al.*, 2007; Ivancic and Hesketh 2000]), as well to novel situations in the simulator, and real world driving.

Our future research plans, building on our ongoing longitudinal cohort study on prediction of driver safety in PD and this pilot study, include developing an effective driver rehabilitation program in PD that includes simulator training. We will test this program in a randomized manner against a standard intervention (e.g., driver improvement classes). Our outcome measures will include a road test before and long time after the intervention and collection of real life outcome measures such as state records on crashes and citations, and driving cessation during the follow up.

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