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Research Article

Use of a driving simulator to improve on-road driving performance and cognition in persons with Parkinson's disease: A pilot study

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Background/aim: *The use of simulators as an assessment and intervention tool for driving is an emerging field in occupational therapy. We investigated the potential usefulness of a driving simulator to improve on-road skills and cognitive functions in drivers with Parkinson's disease (PD).*

Method: *Fifteen participants with PD, and Hoehn and Yahr stages between 2 and 3 participated in this pre–post comparison study. Twelve of the 15 individuals (median age (Q1–Q3), 68 (63.5–72.5); 10 men) completed 10 hours of training in a high-fidelity driving simulator. A practical road test as well as off-road cognitive and simulator tests were administered at pre-training and post-training.*

Results: *Nine participants, who passed the road test before training, passed at post-training. Furthermore, all three participants who initially failed the on-road test passed after training. Participants' performance improved significantly from pre- to post-training on two cognitive tests: (i) the Montreal Cognitive Assessment and (ii) Dot Cancellation test.*

Conclusion: *This pilot study demonstrates the potential usefulness of a simulator to improve on-road driving and driving-related cognitive skills in PD. Adequately powered randomized controlled trials are needed to further expand this field of study.*

KEY WORDS *cognition, driving, Parkinson's disease, rehabilitation.*

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Introduction

Parkinson's disease (PD) is a neurodegenerative disorder that leads to progressive deterioration of motor and non-motor functions (Chaudhuri, Odin, Antonini & Martinez-Martin, 2011; Lees, Hardy & Revesz, 2009), which eventually interfere with performance of instrumental activities of daily living (iADLs; Hariz & Forsgren, 2011). A very important iADL that is affected by PD is driving. An evidence-based review found that cognitive deficits (executive dysfunction and visuospatial impairments) are accurate predictors of on-road driving in PD (Crizzle, Classen & Uc, 2012). In addition, the Hoehn and Yahr (H&Y) classification, a commonly used description of progression of PD symptoms, was associated with self-reported collisions (Dubinsky *et al.*, 1991), simulated collisions (Zesiewicz *et al.*, 2002) and on-road driving performance (Wood, Worringham, Kerr, Mallon & Silburn, 2005). In particular, individuals with mild to moderate symptoms of PD (H&Y 2 and 3) were at an augmented risk for collisions when compared to those in stage 1 or healthy individuals (Wood *et al.*, 2005). The use of driving simulators by occupational therapists as a standardised, reliable and valid method to assess and train driving performance in older adults and drivers with various neurological conditions is increasing (Classen & Brooks, 2014; George, Crotty, Gelinas & Devos, 2014; Hird, Vetivelu, Sasposnik & Schweizer, 2014; Lee, 2004). Driving simulators have the unique capability of interactively engaging the visual, motor and cognitive skills needed for driving in an immersive setting without jeopardising the safety of the driver (Akinwuntan, Wachtel & Rosen, 2012; Classen & Brooks, 2014; Devos, Ranchet, Akinwuntan & Uc, 2015). In a pilot study, the feasibility of using a simulator to improve driving skills in four patients with PD was investigated (Uc, Rizzo, Anderson, Lawrence & Dawson, 2011). After three training sessions, all patients demonstrated reduced collisions in the simulator. In addition, three patients showed remarkable improvements on navigation and visual search tasks (Uc *et al.*, 2011).

Given these encouraging results, we investigated the potential to improve on-road driving and cognitive skills in non-demented drivers with mild to moderate PD using the same driving simulator training programme that was beneficial for stroke (Akinwuntan *et al.*, 2005; Devos *et al.*, 2009) and multiple sclerosis (Akinwuntan, Devos, Kumar, Smith & Williams, 2014). We hypothesised that there will be improvements on a standardised on-road test and on visual search and executive function tests after 10 hours of simulator-based training.

Methods

Participants

Individuals diagnosed with idiopathic PD according to the UK Brain Bank Diagnostic Criteria (Twelves, Perkins & Counsell, 2003) were recruited from the Movement Disorders Clinic of Georgia Regents University and the Charlie Norwood Veterans Affairs Medical Center by a movement disorders specialist (J. M.). Inclusion criteria were: (i) between 25 and 75 years of age; (ii) H&Y stages 2 or 3 during on-medication; (iii) Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) score ≥24; (iv) a valid driver's licenses; and (v) at least 20/60 of binocular acuity and 140 degrees of peripheral field of view in accordance with the state of Georgia driving laws. Individuals with (i) uncontrolled diabetes mellitus, (ii) chronic fatigue syndrome, (iii) fibromyalgia or (iv) other neurological conditions, including dementia, stroke, multiple sclerosis, traumatic brain injury, were excluded. Individuals with a history of (v) substance abuse or (vi) psychiatric problems were also excluded. All participants consented by signing a document approved by the Georgia Regents University Human Assurance Committee, which succinctly explained the study protocols.

Pre- and post-training assessments

General demographic and medical information

For the general medical history documentation, H&Y stages (Hoehn & Yahr, 1967) were confirmed by staff neurologists who also administered the Activities of Daily Living and Motor sections of the Unified Parkinson's Disease Rating Scale (UPDRS II and III) in the on-medication phase (Fahn, Elton, & Unified Parkinson's Disease Rating Scale Committee, 1987). Participants were also interviewed about the duration of the disease and then assessed using the Montreal Cognitive Assessment (MoCA; Nasreddine *et al.*, 2005), Barthel Index (Mahoney & Barthel, 1965), Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983) and Epworth Sleepiness Scale (ESS; Johns, 1991) questionnaires. For the general driving history documentation, participants answered questions on their driving experience, average mileage driven per year and number of traffic violations and collisions in the past five years.

Vision

Binocular acuity for far vision was administered using Keystone Vision Software.

Road test

Participants' practical on-road driving ability was evaluated during a 45-minute drive through a standardised course around the Central Savannah River Area of Augusta, GA. The route traverses areas with low-density to high-density traffic situations include residential, city, interstate and expressway roads. Adherence to different speed limits (25–70 mph), navigating through intersections and non-protected left turns, lane keeping/changing, merging with other traffic, was evaluated using a 16-item checklist. The test was administered in a vehicle with automatic transmission, adapted for safety (dual controls) and registered with the Georgia Department of Driver Services by a certified driving instructor with over 33 years of experience in the assessment of older, disabled and novice drivers. A maximum score of 50 points was obtainable on the road test. To pass the road test, an individual needed to score of 45 or more points, which indicated minor or no concerns. The pass–fail classification and the raw scores on the road test constituted the main outcome measures in this study.

Simulator test

For the simulated drive assessment, participants were seated in a Plymouth Acclaim 1991 sedan and were instructed to use all operational parts of the vehicle (steering, gas and brake pedals, seat belt, rear mirror and turn signals) as in real life to navigate through different traffic scenarios displayed on three 9 sq. ft. screens, with a total of 135 degrees field of view. All the scenarios were developed using the STISIM simulator software from STI, Inc. The first scenario was a familiarisation course with mild traffic that was approximately 1.5 mile long. This scenario was used to get the participants acquainted with the driving simulator and its operational parts. Following verbalization of familiarity with the simulation system, participants were presented a 9.5 mile evaluation scenario that was scripted to simulate regular commute traffic at about 10:30 AM in the Central Savannah River Area of Augusta, GA. During the drive, measures including number of collisions (sum of off-road and on-road crashes), traffic violations (sum of speeding tickets and traffic lights violations) and lane edge crossings were automatically documented in the simulator output. Participants' response time was then tested using a 1.5-mile long scenario in which five large 'STOP' signs suddenly appeared at specific but different times in the middle of the screen. Participants were instructed to maintain an average speed of 45 mph during this drive. The time between the appearance of each stop sign on the screen and coming to a complete stop from an average speed of 45 mph was documented in the simulator and tagged the 'complex response time (CRT)'. The CRT was further separated into (i) seeing time (ST), that is the time between the appearance of the stop sign and lifting the foot off the accelerator pedal; (ii) movement time (MT), that is the time between lifting the foot off the accelerator pedal and pressing the brake pedal; and (iii) brake time (BT), that is, the time between pressing the brake pedal and coming to a complete stop. The CRT, ST, MT and BT data used in the study analyses were the averaged values from the last four STOP signs.

Cognition

The cognitive assessments comprised of the Rey–Osterrieth Complex Figure (ROCF; Fastenau, Denburg & Hufford, 1999), Trail Making Tests (TMT) A and B (Tombaugh, 2004), Useful Field of View (Ball, Roenker & Bruni, 1990) and the US version of the Stroke Driver Screening Assessment (SDSA), which encompassed the Dot Cancellation, Directions, Compass and the Road Sign Recognition tests (Akinwuntan *et al.*, 2013).

Intervention

Participants underwent 10 hours of training in a driving simulator once per week over a period of 12 weeks at most. The training programme consisted of 10 different 3.5 mile training scenarios that targeted critical on-road driving skills such as lateral position on the road, navigating curves, changing lanes, coming to a full stop at crosswalks, speed adaptations at low and high speed, road sign recognition, anticipation, hazard perception and overtaking manoeuvers. The contents of each training programme were individualised for each participant based on their performance on the road test, neuropsychological tests and the simulator evaluation. The selected driving skills were trained intensively and repeatedly. Each training session comprised five minutes of welcoming the patients, 45 minutes of actual simulator training with feedback after each simulation and 10 minutes of feedback of the general session. Active and cognitive engagement was promoted by asking the participant to identify and suggest ways to overcome the driving problem. When patients had difficulties identifying the problem or exhibited limited awareness of their driving problems, feedback was provided by the investigator.

Statistical analysis

The small dataset precluded parametric analyses. Therefore, medians and interquartile range (Q1–Q3) were reported for ordinal, interval and ratio variables. Frequencies and percentages were used for nominal variables. Wilcoxon signed-rank tests were employed to investigate differences between post- and pre-training performance. P values < 0.05 were considered significant.

All analyses were performed with the statistical program SAS Enterprise 5.1.

Results

Fifteen participants were enrolled within a 15-month period. Three participants opted out of the study during the pre-training phase because they experienced discomfort in the simulator. There was no association between the onset of discomfort in the simulator and

TABLE 1: *Demographic, medical, driving and visual data of the 12 participants who completed training*

Age, years	68 (63.5–72.5)
Gender, male (%)	10 (83.3)
Hoehn and Yahr stage (ON)/5 (↓)	2 (2–2)
UPDRS Activities of Daily Living (ON)/52 (↓)	11 (9–13)
UPDRS Motor Assessment (ON)/108 (↓)	29 (24.5–32)
Disease duration, years	6 (3–6)
MoCA	24 (21–27)
Barthel Index/100 (↑)	97.5 (95–100)
HADS − total score/42 (↓)	8 (8–11)
ESS/24	9 (6–12)
Driving experience, years	51 (47–57)
Annual mileage	10,000 (8750–15,000)
Traffic violations in the past five years	0 (0–0)
Collisions in the past five years	0 (0–0)
Binocular acuity (↓)	25 (25–45)

Values are median (quartile 1–quartile 3) except where indicated; ↓, worse performance with higher scores, ↑, better performance with higher scores.

UPDRS, Unified Parkinson's Disease Rating Scale; MoCA, Montreal Cognitive Assessment; HADS, Hospital Anxiety and Depression Scale; ESS, Epworth Sleepiness Scale.

performance on all other pre-training assessments. The demographic, clinical, visual and driving data of the 12 participants who completed all aspects of the study are displayed in Table 1.

Following 10 hours of training to improve driving-related skills in a high fidelity simulator, participants' performance on the real-life on-road test appeared to improve from pre- to post-training, but the difference was not statistically significant (Table 2). Per the simulator variables, a reduction in the median number of collisions, traffic violations, lane edge crossings and complex response time was observed from pre- to post-training (Table 2). Again, none of the variables reached statistical significance. The closest to statistical significance was the reduction in total number of traffic violations (P = 0.08). Further data inspection revealed that nine out of the 12 participants committed less traffic violations after training; two committed two violations before and after training; whereas only one participant had no violation before training but had two after training.

Participants' performance on the MoCA test significantly improved from pre- to post-training (P = 0.008). Participants' also completed the Dot Cancellation test in a significantly shorter time (P = 0.0005) and with significantly fewer errors (P = 0.001) after training (Table 3).

As this is a pilot study, we also scrutinised the data on individual level. Figure 1 shows the individual scores on the on-road test (1a, lowest to highest performance at pre-training) as well as the significant cognitive tests

TABLE 2: *Pre- and post-training performance in simulator tests (*n = *12)*

Variable	Pre-training	Post-training	*S*	*P* value
Total on-road score/50 (↑)	46 (45–48)	47 (46–48)	11	0.31
Simulator variables				
Collisions, total	0 (0–1)	0 (0–0)	−1.5	0.25
Traffic violations, total	7 (4–8)	3 (2–5)	−11	0.08
Lane crossings, total	5 (3–9)	4 (3–6)	−3.5	0.63
Complex response time, seconds	4.15 (3.41–5.18)	3.74 (3.67–3.97)	−3.5	0.56
Seeing time, seconds	0.57 (0.49–0.59)	0.57 (0.43–0.69)	−0.5	1.00
Movement time, seconds	0.40 (0.32–0.43)	0.42 (0.29–0.46)	−1	0.56
Brake reaction time, seconds	3.17 (2.62–4.15)	2.83 (2.65–3.09)	−5.5	0.31

Values are median (quartile 1–quartile 3). *S*, Wilcoxon Signed-Rank test.

TABLE 3: *Pre- and post-training performance in on-road and cognitive tests (*n = *12)*

Variable	Pre-training	Post-training	*S*	*P* value
MoCA/30 (↑)	24 (21–27)	26 (24–30)	26	0.008
ROCF/36 (↑)	32 (31–35)	34 (33–35)	10	0.21
TMT A, seconds (↓)	60 (52–75)	53 (41–82)	−10	0.43
TMT B, seconds (↓)	194 (125–298)	134 (96–215)	−15	0.27
UFOV speed of processing, milliseconds (↓)	37 (17–133)	42 (17–107)	3	0.82
UFOV divided attention, milliseconds (↓)	192 (55–450)	193.45 (23–420)	−5	0.70
UFOV selective attention, milliseconds (↓)	352 (240–500)	418 (240–500)	4	0.77
Dot Cancellation time, seconds (↓)	736 (607–900)	591 (505–693)	−39	0.0005
Dot Cancellation errors (↓)	9.5 (3.5–33)	8.5 (6–19)	33	0.001
Directions/32 (↑)	26.5 (15–32)	32 (23–32)	3	0.72
Compass/32 (↑)	18 (8–22)	14 (10–22)	−1	0.98
Road Sign Recognition/12 (↑)	7 (4–9)	8 (5–9)	5	0.67

Values are median (quartile 1–quartile 3). ↑, better performance with higher scores; ↓, worse performance with higher scores.

MMSE, Mini-Mental State Examination; MoCA, Montreal Cognitive Assessment; ROCF, Rey–Osterrieth Complex figure; TMTA, Trail Making Test A; TMTB, Trail Making Test B; *S*, Wilcoxon Signed-Rank test; UFOV, Useful Field of View.

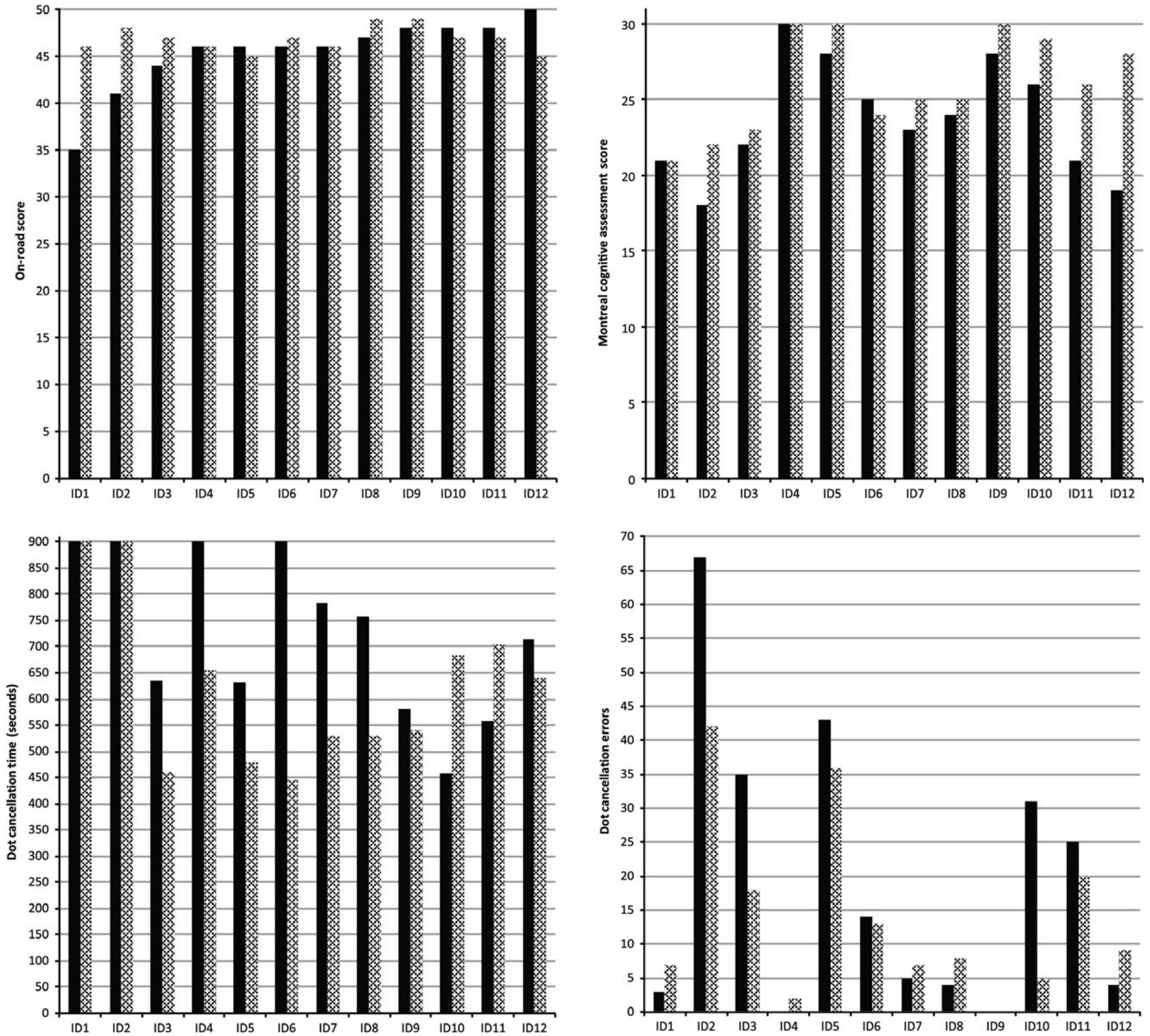

FIGURE 1: *Individual performance on on-road test, and significant cognitive tests at pre- and post-training.*

(1b–d) at pre- and post-training. Nine of the 12 participants passed the on-road test at pre-training (≥45 of 50) and all repeated passing performances at post-training. It must be noted, however, that four of the nine participants (IDs 5, 10, 11, and 12) deteriorated from pre- to post-training but still did not score below the clinical threshold of passing the on-road test. All three participants who initially failed the road test (IDs 1, 2, and 3) passed after the 10-hour training programme. There was no clear pattern of improvement on the on-road test and across the three significant cognitive variables.

Discussion

In this pilot study, we evaluated the potential of using a driving simulator to improve on-road driving skills and driving-related cognitive skills in non-demented drivers with mild to moderate PD.

A clinically important finding of this pilot study is that the three participants who initially failed the on-road tests all went on to pass after training. Although these three individuals had valid driver's licenses, they had self-decided to stop driving due to reduced confidence in their abilities. After participation in this pilot study, two of the three participants resumed driving after performing and passing an official driving evaluation administered by an independent and certified driving evaluation expert. In addition, the nine participants who passed initially retained passing performance after training. Similarly, the improvements, such as the reduction in number of collisions, observed in participants' performance on the driving measures assessed in the simulator after training can be said to be clinically relevant despite not being statistically significant. For instance, a reduction in number of collisions or traffic violations by only one may be statistically insignificant; yet, it could be the one collision or traffic violation that potentially could result in fatalities.

Visual scanning was found to be greatly reduced in drivers with PD (Classen *et al*., 2014; Devos *et al*., 2013; Uc *et al*., 2006) and suggested as one of the key cognitive functions to be targeted in non-contextual rehabilitation training of driving in PD (Devos *et al*., 2015). Significant improvements in a test that assesses visual search skills (Dot Cancellation test) and in another that includes assessment of executive function (MoCA) observed in this study also confirm our hypothesis and support the findings of a previous pilot study (Uc *et al*., 2011). Due to the importance of visual scanning when driving, it is pertinent that an effective driving training programme should be capable of improving performance in this specific cognitive domain.

Limitations

In spite of these promising findings, we acknowledge obvious limitations of our pilot study. Our inclusion criteria led to a cohort of participants, majority of whom passed the on-road test (main outcome measure) prior to training. Our sample size is small and most likely reduced the likelihood of finding statistically significant improvements on many of the assessment variables. Yet, this pilot study contributed to our knowledge about the use of simulation to train driving in PD. The absence of a control group is another limitation of the pilot study as were unable to control for practice effects in the simulator or other activities not related to the study.

Conclusion

This pilot study shows the potential usefulness of a simulator-based training programme to improve the on-road skills and driving-related cognitive skills of persons with mild to moderate PD. The veracity of our findings will need to be confirmed in adequately powered randomized controlled trials. Future research is also warranted to investigate whether driving simulators are feasible in the clinic in terms of cost-efficiency when compared to conventional occupational therapy.

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