Performance of Drivers with Parkinson's Disease under the Effect of Cognitive Overloading: Insinuation for Assessment and Training

[1] Hoe Lee, PhD; [1, 2, 3] Torbjorn Falkmer, PhD; [1]Derserri Yanting Chee, Bsc OT (Honours)

[1]School of Occupational Therapy and Social Work, Curtin Health Innovation Research Institute, Curtin University,

[2] School of Health Sciences, Jönköping University, Jönköping, Sweden

[3] Department of Rehabilitation Medicine, IKE, Faculty of Health Sciences Linköping University, Sweden

Corresponding author:
Hoe Lee, PhD
Senior Lecturer, School of Occupational Therapy and Social Work
Curtin University, PO Box U1987
Email:Hoe.Lee@curtin.edu.au

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Abstract

Signs and symptoms of Parkinson's Disease include a combination of slowness of movement, increased tone, tremor and loss of postural reflexes. Cognitive changes and dementia can also be found in older people suffering from PD. The excessive expenditure of cerebral resources in multitasks can cause cognitive overload resulting in deterioration of functional performance. Previous research has highlighted that the balance of cognitive overload is essential for safe driving; however, this has not yet been researched in relation to people with PD. When exposed to demanding traffic scenarios, PD drivers who have already coupled with mental inflexibility and sluggish reasoning can reach dangerous level of cognitive overload. The present study employed computation of arithmetic sums as secondary task to investigate the effect of cognitive overloading on older PD drivers. Methodology: A pre-post case-control study design was implemented. Convenience sample of 28 mild to moderate stages of PD drivers and 30 age-matched healthy controls were recruited and their motor and cognitive functions were assessed. Participants were then assessed twice using a driving simulator: one with exposure to the secondary task and the other without. Results: When compared with healthy controls, PD drivers scored lower in motor and cognitive psychometric assessments and performed less competently in driving assessments ($P<0.001$). PD drivers drove more cautiously and took more time to complete all the driving tests when compared with the healthy counterparts ($P < 0.001$). With the distraction of the secondary task, both the performance of PD drivers and controls declined, but PD drivers to a great extent. The Trail-Making Test-B was found to be valuable in predicting the overall performance of PD drivers. Conclusion: The ability of PD participants was observed to have significant deterioration in driving through T-junctions and roundabouts. PD drivers should avoid multitasks in driving as cognitive overload result from which can compound the problem of indecisiveness of the drivers; leading to inconvenience or dangers to other road users. Training on PD drivers should emphasize on intersection manoeuvre management.

Key words: cognitive deficits; driving, driving simulator, cognitive overload, Parkinson Disease

Introduction

PD is the second most common neurological disease in Australia. One out of 100 people over the age of 65 and two out of 100 people over the age of 85 are suffering from Parkinson's Disease worldwide (Jankovic, 2008). In addition to motor problems, PD can also affect neural networks transmitting signals for many important cognitive functions: attention, information processing and memory (Uitti, 2009). Cognitive changes and dementia can also be found in older people suffering from PD. The driving environments are full of distractions and unpredictable events; therefore, able to pay full attention to the changing traffic is essential for safe driving (Lavie, 2005). Deficits in cognitive ability of PD drivers can have a substantial impact on driving performance and increase risk of accidents and fatalities on Australian roads (Austroads, 2003).

In normal driving, drivers register large amounts of information while simultaneously plan, prioritize and coordinate manifold operational devices of the car (Uc & Rizzo, 2008). It is common to observe drivers dangerously over-stretch their mental capacity to non-driving activities, such as engaging in mobile phone or conversing with passenger (Neale, et al., 2002). The excessive expenditure of cerebral resources in multitasks can cause cognitive overload resulting in deterioration in performance (Fox, Park, & Lang, 2007). When exposed to demanding traffic scenarios or distracted by non-related driving tasks, PD drivers who have already coupled with mental inflexibility and sluggish reasoning are more easy to reach a dangerous level of cognitive overloading (Stolwyk, et al., 2006).

Previous research has highlighted that the balance of cognitive overload is essential for safe driving (Stolwyk, et al., 2006); however, this has not yet been researched in relation to people with PD (Devos, et al., 2007; Klimkeit, Bradshaw, Charlton, Stolwyk, & Georgiou-Karistianis, 2008). Mental arithmetic tasks have been extensively used in the exploration of human cognitive abilities, since it requires complex mental function and problem solving (Ryu & Myung, 2005). Several studies have employed the mental arithmetic as proxies for conversations and multitasks to assess driving behaviours (Haigney & Westerman, 2001; Patten, Kircher, Ostlund, & Nilsson, 2004). The current study employed the computation of arithmetic sums as secondary task to investigate the effects of cognitive overloading on people with PD in driving. By trialling alternative methodology to assess cognitive overloading, the study was valuable in developing a comprehensive assessment protocol for PD drivers.

Methodology and experimental design

A pre-post case-control study design was implemented for this study. The independent variables investigated in this study were the presence of the concurrent task and participant group. Dependent variables included (a) driving behaviours: number of road crashes and collisions, speeding, missing stop-signs, centre-line crossings, road edge excursions and stops at traffic lights and (b) concurrent task performance: the response time and accuracy to the visual stimulus.

<u>Study sample</u>

Fifty eight participants; 28 PD participants and 30 controls were recruited for this study through convenience sampling. Participants from the healthy group were recruited through the use of public advertisements in the community whereas the PD group was recruited through random selection from the membership database of a previous driving simulator study (Cordell, Lee, Granger, Vieira, & Lee, 2008), the local clinics and the Parkinson's Association. Ethics approval to conduct the study was granted by the Human Research Ethics Committee of Curtin University (Approval number: OTSW-17-09). Informed consent to participate was obtained from all participants. Participants, who had been diagnosed suffering from PD by a neurologist, were initially screened for visual, cognitive and hearing impairments by using a medical and driving history checklist. A summary of the participant demographics is presented in Table 1.

Table 1: Demographic information data and driving history of the participants

Variables	**PD group (n=28)**	**Control group (n=30)**
	Mean (SD) [Range]	**Mean (SD) [Range]**
Age	64.3(2.1)[56-81]	62.3(1.7)[53-77]
Years of driving	42.9(3.3)[33-57]	44.3 (1.9)[28-54]
Hours of driving per week	6.3(2.19)[0.4-22]	15.3 (3.1)[2.9-41]
Hoehn & Yahr Stage of PD	1.7 (0.6) [1- 3]	
	(%)	**(%)**
Gender (male)	12 (43)	14(46)
Gender (female)	16 (57)	16 (53)
Hand dominance (right)	13 (46)	12 (40)
Hand dominance (left)	3 (11)	4 (17)
Education level (University) Education level (Year 12)	12 (43) 6 (40)	11 (57) 4 (27)
Self-report past traffic infringement (No)	27 (96)	25 (83)

When comparing the PD and control groups, there was no significant difference in baseline profile with regards to age, gender, years of driving and educational level ($p > 0.05$). None of the participants reported other neurological and/or psychiatric impairments. A group difference (p=0.0031) was found in the hours of driving per week, with the mean hours of driving being 15.3 for the controls and 6.3 for the PD group. However, the number of hours driven per week indicated that both groups comprised of regular drivers.

Procedures

Baseline measure of motor and cognitive abilities, psychometric assessments was obtained for all participants. An operational manual was used to ensure the uniformity of data collection procedures among participants. The psychometric assessments administered by the researcher took approximately 40 minutes to complete. The assessment in a driving simulator consisted of a practice trial and two experimental trials. The practice trial covered a road of 5 kilometres with unsophisticated visual and graphic information, in which participants had the opportunity to practice the operation of an add-on button device for the concurrent task. The participants were encouraged to familiarize themselves with the steering, speed control, manoeuvring through intersections and perform emergency brakes for risk management tasks. The experimental trials consisted of two trials of a 20 km simulated driving; whereas, a concurrent task (computation of arithmetic sums) was added in the second trial.

Instrumentation and apparatus

A number of instruments and measurement tools including screening assessments, psychometric assessments, PC-based STISIM driving simulator and the E-Prime computer-based assessment tool were employed to assess participants. The psychometric assessments selected were based on a literature review of their use in drivers with PD (refer to Table 2). All participants were tested using the fully interactive STISIM driving simulator (Allen, Rosenthal, Aponso, & Park, 2003) at Curtin University. The validity of the driving simulator has been established (Lee, Lee, Cameron, & Li-Tsang, 2003) and high transferability between simulated and on-road driving performance had been reported (Lee, Cameron, & Lee, 2003).

Table 2: Screening tools administered & methods used in initial assessment

Tools & methods used	Areas assessed in initial screening/Purpose	Reasons for adoption/ Evidence to be used to assess cognitive functions related to driving
Cognistat (Kiernan, Mueller, Langston, & Van Dyke, 1987).	Individuals were screened for cognitive impairment. People screened with moderate-severe or severe cognitive deficits were excluded.	More reliable in its report of cognitive impairment compared to the Mini-Mental State Examination
Driving history checklist	Individuals had to be current drivers and be able to present a valid Australian driver's license	Based on driving history assessments used at driving assessment facilities in Western Australia and Australian driving regulations
Medical Checklist	Individuals were screened for confounding variables • Co-morbidities • Medication dosage • Chronic fatigue	Based on driving history assessments used at driving assessment facilities in Western Australia and Australian driving regulations
Snellen Chart	Individuals were screened for visual acuity. Participants required a score of at least 6/12 corrected vision.	Minimum standard for on-road driving is 6/12 correct visions (National Road Transport Commision, 2003)
Stage of Hoehn & Yahr (Hoehn & Yahr, 1967)	Stages of disease severity were reported by their neurologists.	To determine the level of disease severity.
Digit Vigilance Test (Lewis & Rennick, 1979)	The Digit Vigilance Test (DVT) is a measure of sustained attention and psychomotor speed. The DVT has been used widely in the study of a number of neurological conditions	• DVT has high test-retest reliability and has been validated as a measure of sustained attention (Kelland & Lewis, 1996) • Demonstrates the ability to select and focus only on important information whilst ignoring irrelevant information.
Perdue Pegboard (Lafayette Instrument Company, 1985)	The Perdue Pegboard assesses for gross motor movements of hands, fingers, and arms.	• Standardised assessment tool • High test-retest reliability • Good predictive value of driving performance with relatively high sensitivity and specificity
Symbol Digit Modalities Test (Smith, 1982)	The Symbol Digit Modalities Test (SDMT) assesses for learning and cerebral disorders by measuring the efficiency and accuracy of information processing systems.	• High test-retest reliability (0.80) • Substitution tasks are found to be highly sensitive to detecting cerebral dysfunction
Trail-Making Test-Part A & B (Gaudino, Geisler, & Squires, 1995)	The Trail-Making Test (TMT-B) assesses for executive function, visual attention and task switching abilities.	• Norms established for older adults over the age of 65 • Commonly used in driving assessments and is found to be indicative of driving performance in clinical populations such as PD, dementia and traumatic brain injury

The simulator consists of a mid-sized sedan (adjustable seat, brake and acceleration pedals and steering wheel) with an automatic transmission interface (refer to Figure 1). The simulator includes a digital audio output that presents auditory stimuli of real-life driving audio environments such as surrounding wind, police sirens and engine noise. The driving simulator was calibrated to ensure high quality data collection during the experiment.

Figure 1: The STISIM Driving Simulator set up at Curtin University

The experimental trials consisted of a continuous run of metropolitan and country roads. Normal driving environments such as two-way and four-way roads, intersections with and without stop signs were included. In order to assess for the participants' response to sudden events, traffic scenarios that required an immediate response were incorporated. Sensitive driving scenarios were set up to measure how psychomotor and cognitive deficits affect driving behaviors of the PD participants. The assessment sessions remained brief, 15 minus each, to minimize influencing factors such as fatigue and simulator motion sickness (Stern & Davis, 2006).

Participants' operational and tactical level of driving skills (Michon's driving model, 1985) were assessed in three key areas, namely, Rules and Regulations, Risk Management and Intersection Manoeuvring (Refer to Table 3). Driving behaviours not collected by the driving simulator were clinically observed and reduced to a *driving performance score*, with reference to previous simulator studies (Lee, Cameron & Lee, 2003) and standard of current driving assessments in Australia (Austroads, 2003).

Table 3: Summary of assessment criteria for driving performance

Key Assessment Criteria	Scoring (one point for each item)
<u>Rules & Regulations</u>	
• Adherence to speed signs (±5km/hr)	• Kept range of speed between ±5km/hr of the assigned speed
• Keep on left lane	• Automatically followed 'Keep Left' rule
• Neck turning to check side mirrors and blind spot when changing lanes	• Checked traffic by looking at mirrors
• Complete stop at STOP signs	• Car performed complete stop before stop sign and avoid collision (fully press and hold break) • Slowed down but collided with cross traffic • Observed roads on left and right with neck turns and accelerate only when roads on both sides are clear
• "After the intersection, continue straight"	• Continued straight after intersection
• The trucks up ahead are too slow, try to pass them be aware of oncoming traffic"	• Obeyed overtaking instruction
• " You are low on gas, pull up to the gas station on the left"	• Slowed down when approaching gas station • Entered and stopped at gas station
<u>Risk Management</u>	
• Avoid collision with vehicle and pedestrians	• Able to avoid collision
• Slowing down when approaching oncoming vehicles	• Slow down as vehicle/pedestrian/dog approaches
• Effective manoeuvres to avoid collision	
• Maintaining appropriate distance obstacles	
<u>Intersection Manoeuvring</u>	
Intersection- Red light	
• Decelerate- visually assess distance to intersection line • Maintain safe lane position • Obeying to auditory stimuli "continue straight after intersection" • Selecting the correct lane (Left lane) • Stop—fully press and hold brake • Observe/ visually tracking status of traffic light	• Slowly decelerate (smooth brake)- visually assesses distance to intersection line • Stop at intersection—fully press and hold brake • Observe/ visually attentive to status of traffic lights and presence of approaching pedestrians • Selected the correct lane (Left lane) • Obeyed auditory stimuli "continue straight after intersection"
Intersection- green light	
• Ensured the safety of pedestrians by checking their left and right • slowly accelerate to maintain speed • maintain safe lane position (keep left	• Checked roads on both sides are clear of pedestrians and traffic before proceeding • Slowly accelerate to maintain speed at 90km/h • Kept to the left lane • Minus 2 points if roceeds when light is still red)

E-prime (Schneider, Eschman, & Zuccolotto, 2002) is a program that enables researchers to design and conduct computer-based experiments, where data of millisecond precision can be gathered (Ranzini, Dehaene, Piazzaa, & Hubbard, 2009). During the trial 2, the participants were exposed to mathematical equations on a display (Refer to Figure 1) and they were required to respond the stimulus and continue driving. The current methodology to measure cognitive overloading was adopted from the secondary task reaction time paradigm, in which reaction time (RT) is a representation of cognitive work load: slower the RT to secondary task indicates declining cerebral resources (Lang, Bradley, Park, Shin, & Chung, 2006). The paradigm was developed under the limited capacity model of attention (Navon & Gopher, 1979), in which humans are regarded as information processors with a reduced mental capacity when distracted by concurrent task.

The E-prime software gathered participants' reaction time (defined as the time interval between the presentation of the visual stimulus and the corresponding motor response through the add-on device) and number of accurate response to the concurrent tasks. The arithmetic sums as the visual stimuli were displayed on high contrast background at every 9-second intervals. Participants triggered dichotomous response through the button: 'yes' for a correct math equation and 'no' for an incorrect stimulus. When PD drivers are overloaded with a secondary task, their driving performance was hypothesized to be declined and the response time to the concurrent task increase.

Satistical analysis and data management

The data gathered from the psychometric tests, clinical observations and driving simulator were entered into Microsoft Excel spreadsheets. Statistical analyses were conducted using the Statistical Analysis System (SAS) version 9.1 for Windows (SAS Inc, 2010). A repeated measure of regression analysis was performed using the *driving performance score* as the dependent variable. Independent variables include mean response time to the concurrent task, trial number, psychometric test scores and group (PD or control). The model was fitted using a 'backwards elimination' strategy, where variables were removed from the model one at a time, until the *p*-value associated with each variable left in the model was <0.05. The level of statistical significance was defined as $\alpha = 0.05$. All results were rounded off to two decimal places except for *P*-values that were rounded off to 3 decimal places.

Results

PD participants adhered to driving speed well below the designated limit (drove at 45.6 km/hr in 50 km/hr zone; and 47 km/hr in 60 km/hr zone) and they observed the road rules and regulations closely (less infringement notice for speeding and running through red-lights). In driving through high demand traffic scenarios such roundabouts or T-junction, PD drivers were observed being hesitant to merge into traffic and use of indicators. It was also observed that both groups had exceeded the designated speed limit by more than 5km/hr speed after taking over cars or manoeuvring through intersections or obstacles. One driving scenario required the PD drivers to avoid colliding with a truck backing out a driveway located 70 metres away from a T-junction. PD approached the T-junctions cautiously with slow speed and accelerated after passing the intersection; consequently, many crashed into the back of the moving truck. The PD participants were observed crossing the medium strip of dual carriageways in turning and stopping far behind the double white-lines of traffic-light controlled intersections. Uncoordinated control of operational devices of vehicle in emergency stopping was also noted in PD group.

Analysis of results from psychometric assessments

This current study assumed that results from the psychometric tests represented the baseline cognitive and motor abilities of participants. It is expected that the independent t-test on the score of psychometric tests would differ significantly between the comparison groups (refer to Table 4); however, the only two assessments showed significant difference in PD and control group are Perdue pegboard and TMT-B.

Table 4: Comparison of Psychometric tests for the PD and control groups

Variable ***Psychometric Tests***	**PD group (n=28)** **Mean[SD]**	**Control group (n=30)** **Mean [SD]**	***t*-test** ***p*-value**
Perdue Pegboard	41.2[7.3]	45.3[5.1]	0.005*
Trail Making Test B (TMT-B)	2.1[0.4]	0.9[0.4]	0.004*
Symbol Digit Modalities Test (SDMT)	46.8[5.17]	45.3[5.9]	0.214
Digit Vigilance Test (DVT)	4.3[0.5]	3.2[0.5]	0.237

* Statistical significance ($p<0.05$)

Analysis of driving performance in participants

Independent sample *t*-tests were used to compare the performance of the PD and control in trial 1 and trial 2 (refer to table 5). The difference in number of collisions (either with cars or objects on the roadside) between the PD and control group in trial 1 is not significant. When the concurrent task was added in trial 2, the number of collisions between the groups became significant: increased by 0.44 (from 1.48 to 1.92) in PD drivers and 1.27 (from 1.83 to 3.10) in the controls.

The control group completed trial 1 and trial 2 faster than the PD and the time difference is significantly ($p<0.001$ in trial 1 and $p=0.008$ in trial 2). Control has reduced 6.4 seconds in completing trial 2, whereas, drivers with PD reduced 62.5 seconds to complete the same trial. Paired t-tests were conducted for both PD and control groups in Run Length (total time to complete the trial), there was no significant difference in between first and second trial in each group. Controls performed better in Intersection Maneuvering and the score difference in both trials were significant (p=0.006 in Trial 1 and p = 0.029 in Trial 2).

Table 5: Comparison of descriptive measurement of driving performance and concurrent task between groups

Variable	PD Group (n=28) Mean [SD]	Control group (n=30) Mean [SD]	*t*-test *p*-value	PD group (n=28) Mean [SD]	Control group (n=30) Mean [SD]	*t*-test *p*-value
Driving	Trial 1	Trial 1		Trial 2	Trial 2	
	(without concurrent task)			*(with concurrent task)*		
Collisions	1.48 [1.2]	1.83 [0.9]	0.279	1.92 [2.1]	3.10 [0.8]	0.031*
Pedestrians hit	0.68 [0.6]	0.3 [0.07]	0.0428	0.89 [0.62]	0.42 [0.4]	0.634
Speeding	3.89 [4.4]	5.31 [3.8]	0.566	5.41 [3.1]	4.89 [3.1]	0.231
Traffic Light tickets	-	-	0.147	0.06 [0.41]	0.5 [0.3]	0.627
Stop signs missed	0.6 [0.4]	0.41 [0.6]	0.331	0.43 [0.54]	0.45 [0.3]	0.701
Centreline crossings	4.98 [4.8]	5.8 [3.5]	0.464	6.12 [4.8]	8.18 [4.12]	0.100
Road Edge excursions	4.30 [2.1]	3.01 [2.2]	0.223	6.1 [3.8]	4.66[2.9]	0.345
Stop at lights	6.76 [0.9]	3.89 [0.8]	0.288	4.12 [0.64]	5.07 [0.4]	0.089
Run length (secs)	855.92 [49.9]	707.31 [79.3]	0.001*	793.42 [67.9]	713.43 [42.1]	0.008*
Assessment Criteria						
Rules & Regulation	42.1 [2.9]	29.9 [3.5]	0.067	35.8 [5.1]	34[5.9]	0.978
Risk Management	45.1 [5.8]	42.1 [5.51]	0.231	31.4 [2.8]	31.4[6.1]	0.771
Intersection Manoeuvring	32.4 [2.9]	34.8 [3.8]	0.006*	28.4 [5.8]	29.6 [4.2]	0.029*
Driving performance index	89.96 [7.8]	98.83 [5.9]	0.004*	87.7 [7.32]	89.43 [8.1]	0.013*
Concurrent Task						
Correct responses				59.8 [2.1]	42.8 [3.2]	0.004*
Mean response time (ms)				5.2 [3.1]	5.1[1.1]	<0.001*

* Statistical significance (p<0.05)

Box plot of Figure 2 illustrates the differences of *driving performance score* between PD and control groups when compared within groups between trials. The control group scored higher in the *driving performance score* than the PD and the difference is significant (p = 0.004). When driving with the burden of a concurrent task, PD participants scored less in the *driving performance score* (PD mean: 87.8; SD: 7.32 and control mean: 89.43; SD: 8.10) and the score difference is significant between the groups (p = 0.0013). Although the PD group scored lower for both trials, it was surprising that the control group was more affected under cognitive overloading when compared within group between trials: a greater drop in mean score (7.40) as compared to the PD group (2.26) in trial 2.

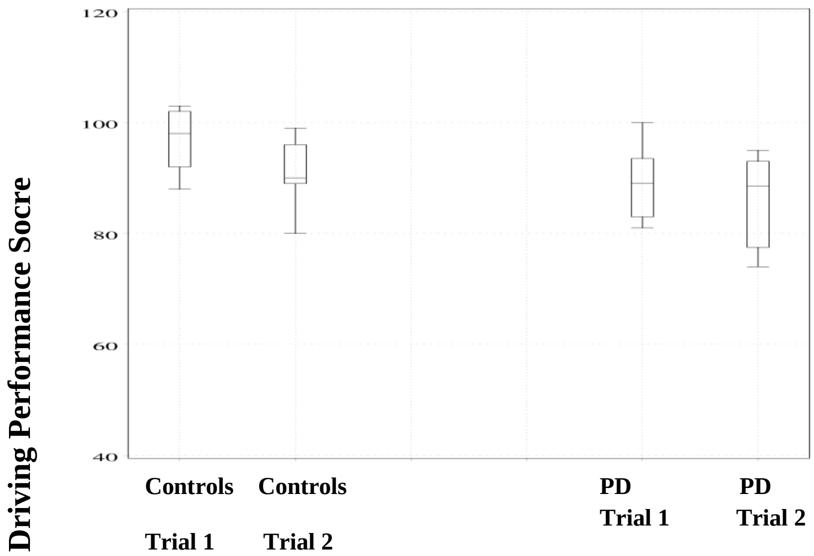

Figure 2: Box-plot showing the difference of driving performance index of participants

Additional findings

Regression model was successfully built (P<0.05) to investigate relationship among participants' motor, cognitive scores and their *driving performance score* in trial 2. Table 6 describes the results from the regression analysis and provides the list of variables analysed as dependent variables to the *driving performance score*. None of the variable is significant in predicting individual's driving performance scores. Using a 'backwards elimination' method, the final regression model (P<0.05) leaves TMT-B the only variable that can predict the drivers' driving score in trial 2, when they are under the pressure of cognitive overloading (*p*-value = 0.032).

Table 6: ANOVA table for repeated measure of regression analysis (before elimination)

Variables	**df**	**F Value**	**P-value**
DVT	1	0.51	0.465
Mean response time to concurrent task	0	0.23	0.628
Perdue Pegboard (combined score)	1	0.02	0.876
TMT-B	1	3.13	0.632
SDMT	1	0.05	0.923

Discussion

PD driver’s performance

PD drivers of current study under performed in the tactical and operational level of driving (Michon, 1985). Duquette et al. (2010) reported PD drivers are easily confused by complex and unfamiliar driving scenarios, slow in reaction and visual scanning while manoeuvring through road junctions. The indecisiveness and slowness in response of PD drivers of the current study were also observed in other study (Cordell, Lee, Granger, Vieira & Lee, 1998). Dominey, Ventre-Dominey, Brouselle, & Jeannerod (1997) suggested that the indecisiveness is not a learning deficit per se; indeed, problem rooted from slow activation or inefficient generation of internal neural responses. Bradykinesia, manifestation of basal ganglia pathology in PD, exacerbates the delay of response time; in addition, exigency of cognitive workload from external sources further dampen the neural transmission process down (Robinson & Rajput, 2005).

PD participants of current study took longer time to complete the simulated driving trials and drove more cautiously. In postulating multi-factorial model of driving, Anstey, Wood, Lord, & Walker (2005) suggested that individual’s beliefs in own driving ability and self-monitoring of driving habits can shape one’s driving behaviours. PD participants in the current study adhered to driving speed well below the designated limit and they observed the road rules and regulations more closely. The PD group of current study were aware of their deteriorating abilities; consequently, they self-regulated driving by adopting a more conservative approach in driving.

When interfered with a secondary task in second trial, all drivers could not keep up the same driving standard as in first trial. Performance of drivers with PD participation deteriorated to a greater extent, suggesting that this population group when under the pressure of cognitive overloading may be at greater risk of compromising their driving skill in operational level. Observations that PD drivers’ skills deteriorated when confronted with the capricious traffic conditions were reported in other study. Stotwyk (2006) investigated the effects of concurrent tasks on PD drivers and recorded driving skills of them deteriorated at road interactions where demand in cognitive workload was recurring.

The Yerkes & Dodson (1980) stipulated that performance of individual is dependent on the cognitive workload imposed on an individual; once overloading exceeds the optimal level of cognitive workload, performance of the individual would deteriorate. PD drivers in the current study were observed to have reached the workload threshold sooner than the healthy controls; they performed significantly poorer at demanding traffic situations afterwards. When concurrent tasks were incorporated in the trial 2, the PD group crashed more when compared with the controls as well.

Harms (1991) reported that in anticipation of complicated traffic scenarios most drivers decelerate spontaneously; however, they accelerate once they have driven past the critical situations. In current study, PD participants approached busy traffic scenarios with cautions; moreover, most accidents happened immediately after passing the intersections or road junctions.

Use of psychometric tests in driving assessment

The TMT are sensitive to detect impairments in executive functioning, visual attention and task switching ability (Gaudino, et al., 1995; Reitan, 1958), which are essential components for higher order executive functioning and multitasking. The sub-test of TMT, TMT-B, had been reported as one of the few instruments that has a predictive value on performance of drivers suffering from dementia and traumatic injury. Current study confirmed the TMT-B was the only test among the results of other psychometric assessments being able to classify PD drivers correctly according to the *Driving Performance Score*: a proxy of driving competence. In a research study into visual search patterns of 79 PD patients and 151 healthy controls, investigators reported that the TMT-B was the best predictor of the drivers' competency in identifying landmarks and traffic signs (Uc, et al., 2006). Carr, Duchek, Meuser, & Morris (2006) advocated employing the TMT-B as routine assessment procedures and suggested individuals taking longer than 180 seconds to complete the test should be considered unsafe in driving (Carr, Duchek, Meuser, & Morris, 2006). The cost effectiveness, reliability and sensitivity to change of cognitive functions over time add merits to employ the test as part of routine driving assessment. TMT-B like other paper and pencil tests for driving assessment does not have strong face validity; therefore, substandard results of which should not be considered as criteria of driving cessation, but an indication of further evaluation is warranted.

Performance of PD in psychomotor test: Perdue pegboard was significantly different from the control ($P < 0.005$). However, based on the regression model, the poor performance of the Perdue pegboard did not show up as "predictor" to driving performance of the individuals. Uitti (2009) reported that decrease in motor ability characterised in PD does not substantially affect the ability of patients to operate a car safely (Uitti, 2009).

Concurrent task and PD drivers

The mean reaction time and number of correct response to the concurrent task were significantly lower in PD group. To trigger a correct response through the add-on device on the steering wheel, PD participants were required to promptly scan the display, compute the arithmetic sums, organize and prioritize visual cues from the roads, while simultaneously maintain the lane position and speed of the cars. Another study using concurrent tasks to investigate visual attention found the same result that the process, prioritization and preparation of response were impaired in the PD patients (Wright, Geffen, & Geffen, 1993).

PD drivers in current study underperformed in concurrent tasks, but they maintained the driving performance in an acceptable safe level. The presence of concurrent task did not increase the number of crashes significantly. The possible reason for the observation could be that PD participants have sacrificed the concurrent task performance in order to maintain a steady level of driving performance. When PD drivers of current study were exposed to concurrent tasks, they regulated their driving behaviours and chose to concentrate on driving. Other literature also reported drivers with PD were more cautious and focused in driving when they were under time pressure to make decisions in a multitask experiment (Verbaan, et al., 2007)

Limitations of the study

Drivers capture and integrate sensory inputs from the road before they respond to the demand of the traffic scenario. The visual information contributes the most to the decision making process (Owsley, Ball, Allman, Jr, & Sims, 2000). When driving through complicated traffic scenarios, able to gather sufficient cues from peripheral visual field is critical for safe driving (Owsley, et al., 2000). Blepharospasm, repeated twitching of the eyelids caused by spasmodic muscular contractions in PD may interfere the steady streaming of the incoming visual information (Elston, 1992); consequently, prevent appropriate subsequent actions to be taken. All PD participants of the current study had been screened by Snellen's Chart; nevertheless, the visual acuity test is sensitive to static visual field deficits, but not blepharospasm. Neither there is a valid test for blepharospasm, nor the effect of which on driving is known in current literature.

Grace, et al (2005) reported that individuals with deficits in sustained attention and information processing scored poorly in the SDMT and the TMT assessments. The test result of them were significantly correlated with the neurological functions and driving ability of people with PD (Stolwyk, et al., 2006). In the current study, there is no difference in the scoring of DVT and SDMT between the PD and control group. The participants who volunteered in the current study cannot be taken as representative of the older PD drivers population, since the sample was not randomly selected but only covered some sectors of the community. However, random sampling is neither possible nor practical in this sort of study. Selection bias is thus unavoidable in the recruitment of participants. The sampling bias of self-selected PD participants who volunteered to the study may be 'superior' in the PD population might have contributed to the contrast of the current DVT and

SDMT test result with previous research. The relatively small sample size of the study could have also made the real between-group difference of the test scores difficult to detect.

The relatively small size of the monitor display of the driving simulator, together with the nature of the computer-generated stimuli from a stationary model car may limit the equipment to assess driving tasks that require complex visual perceptual abilities (Lee, Lee & Cameron, 2003). Although there was only a small percentage of participants (8%) reported some symptoms of motion sickness and none of them required immediate withdrawal from the study, this issue requires attention in future research.

Recommendations for further study

In the current study, the result of TMT-B and the computation of arithmetic sums generated by the E-prime program were capable of predicting the driving outcomes of PD drivers under the pressure of cognitive overloading. The E-prime, used in conjunction of the driving simulator, may be an alternative for on-road assessments, as it provides a better face validity when compared with paper and pencil tests. Further research to include them in clinical application is warranted. Research using eye-tracking technology to pin-point the eye fixations and record the visual scanning paths of PD drivers with blepharospasm can help to gauge the frequency of peripheral visual field sampling of PD drivers. The information can be used to formulate strategy to train PD to drive through complicated traffic scenarios safely.

Conclusion

In general, PD participants of current study were more cautious and safer in driving, however, driving performance of them deteriorated faster and markedly in confronting with complex traffic scenarios. Indecisiveness and slow in response in driving through road intersections can cause inconvenience and danger to other road users. To yield beneficial training outcomes to this particular group, drivers' rehabilitation should emphasize training on road intersections and roundabouts manoeuvre.

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