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# An Investigation into the Impact of Parkinson's Disease upon Decision Making Ability and Driving Performance

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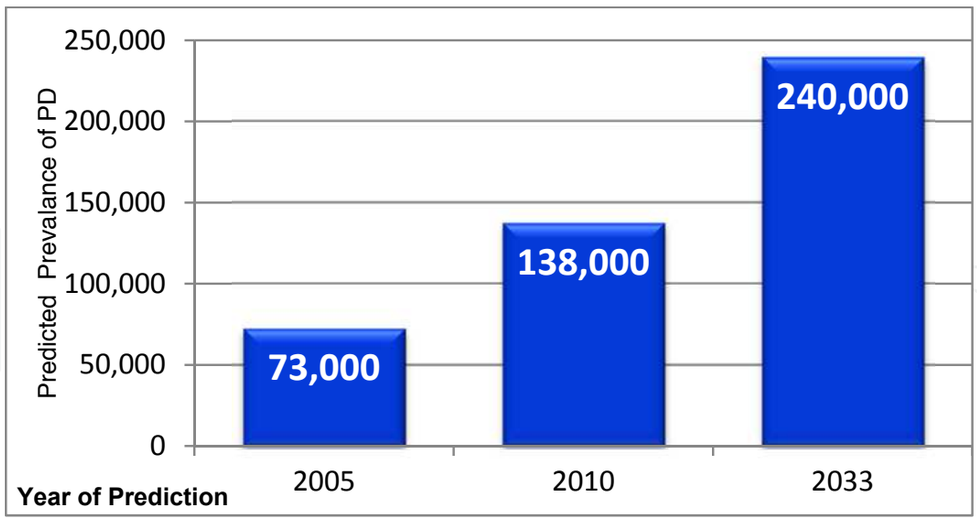
## 1. Introduction

PD is a severe neurodegenerative disease that can impair functional driving performance and increase the risk of accidents and fatalities on Australian roads (Austroads, 2000). In particular, cognitive symptoms of PD can have a substantial influence on driving performance due to the complicated and demanding nature of the task (Uitti, 2009). PD can affect the neural pathways that facilitate essential cognitive processes; such as attention, information processing speed, memory and risk assessment. These processes are all integral to the decision making process (Cools, et at., 2001). Previous research has highlighted that the ability to make accurate and timely decisions is essential for safe driving performance. However, this has not yet been researched in relation to people with PD (Devos, et al., 2007).

### 1.1 Prevalence and aetiology of Parkinson's disease

PD is the second most common neurological disease in Australia; causing impairments in motor control, cognitive functioning and sensation (Access Economics, 2010). PD usually affects people over the age of 50 years. However, the rate of disease progression and severity of symptoms can vary greatly between individuals (Australian Bureau of Statistics, 2004). Australia's aging population is expected to increase the prevalence rate of PD by 40% by 2033 (refer to Figure 1) (Access Economics, 2010).

Recent improvements in the medical and psychosocial treatment of PD has dramatically increased life expectancy, as people with PD now live approximately 12 to 20 years past diagnosis (Access Economics, 2010). PD is currently the sixth highest cause of disease-related driving cessation in Australia (Access Economics, 2010). People with PD generally stop driving at the age of 68; eight years earlier than the general population (Access Economics, 2010). Research into the impact of symptoms upon functional ability will enable




Adapted from: Access Economics, 2010

Fig. 1. Predicted prevalence of Parkinson's disease in Australia 2005-2033

the development of better screening tools and allow health professionals to differentiate between capable and unsafe drivers (Adler, et al., 2000). This may allow capable drivers with PD to retain their licences and current quality of life through active participation in occupations (Innes, et al., 2009). As the number of drivers with PD will rapidly increase due to the aging population, such an initiative will assist in improving road safety (Cordell, et al., 2008).

PD is caused by the progressive cellular death of dopaminergic neurons, predominantly in the basal ganglia in the brain (Arias-Carrión & Pöppel, 2007). Symptoms usually occur after the death of 70% of dopaminergic neurons; causing severe depletion of the neurotransmitter, dopamine (Jankovic, 2007). Dopamine has an extensive role in regulating movement, behaviour, mood and motivation; and may influence learning, time estimation, consequence prediction and awareness of the environment (Arias-Carrión & Pöppel, 2007). The cause of PD is unknown and as the disease cannot be detected prior to onset of symptoms, it is not currently possible to cure PD (Cools, et al., 2001). Severity of symptoms and rate of disease progression vary significantly between individuals. For example, some individuals may experience only minor symptoms 10 years after diagnosis, whilst other individuals may require full time high-support care within six months of being diagnosed with PD (Jankovic, 2007). It is not currently possible to predict how the disease will affect each individual's driving performance, and so assessment must be performed on a case-by-case basis (Jankovic, 2007).

### 1.2 Physical and cognitive symptoms of Parkinson's disease that affect driving

PD can cause a wide range of physical symptoms, which are known to affect driving ability. Common symptoms include motor tremors, bradykinesia, postural instability, rigidity, involuntary movements, generalised slowness and impaired balance (Adler, et al., 2000). People with PD can also experience alterations in sensation; including pain, burning, paresthesia and vestibular dysfunction (Jankovic, 2007). Driving is the most complicated activity of daily living, and even small mistakes can cause severe and potentially fatal crashes (Molnar, Marshall, & Man-Son-Hing, 2006). Driving requires numerous skills and

behaviours to be learnt, coordinated and continuously adapted in a constantly changing environment with time-based pressures (Elvik & Vaa, 2004). Driving therefore places extensive demands upon cognitive abilities, requiring high levels of vigilance, concentration, multitasking, complex reasoning and decision making even when driving over short and/or familiar distances (Devos, et al., 2007).

Physical symptoms of PD have been systematically researched in relation to driving performance. This has contributed to a comprehensive evidence base on the physical effects of PD symptoms upon driving performance (Cordell, et al., 2008; Jankovic, 2007). Drivers with PD have reduced strength and speed of movement, slower reaction times and a diminished ability to turn their head to check mirrors (Adler, et al., 2000; Heikkila, et al., 1997). Drivers with PD also have difficulty in negotiating roundabouts, turning across traffic, driving at high speeds and driving in urban environments (Cordell, et al., 2008; Radford, et al., 2004; Uc, et al., 2009). Drivers with PD are often aware of how their physical limitations influence their driving performance (Kulisevsky & Pagonabarraga, 2009). Consequently, many drivers with PD self-regulate their driving habits by avoiding potentially difficult or risky situations, such as not driving on the freeway, avoiding peak hour or having a co-pilot (Amick, et al., 2007). Factor and Weiner (2002) claimed that the main contributing factors to poor driving performance are PD-related deficits in cognition and visual processing as self-regulating behaviours are very effective in compensating for physical deficits. Uitti (2009) claimed that decline of visual sensitivity, motion perception and cognition are the largest contributing factors to unsafe driving. Further research is required to confirm these claims.

Research into the impact of cognitive symptoms upon driving ability is limited and contradictory. It is difficult to detect the presence of cognitive impairment in PD and to determine the relationship and severity of cognitive impairment on driving performance. The exact prevalence of cognitive impairment amongst drivers with PD is unknown. People with mild to moderate PD have scored significantly lower upon psychomotor and cognitive assessments, showing that PD affects cognition and psychomotor ability at all stages of the disease (Heikkila et al., 1997). However, routine cognitive assessments, such as the Mini Mental Status Examination have low sensitivity, preventing the accurate detection of cognitive deficits in people with PD (Kulisevsky & Pagonabarraga, 2009). Adler and colleagues (2000) stated that 25 to 40% of people in the later stage of PD experience cognitive impairment whilst Factor and Weiner (2002) recorded a lower prevalence rate of 20% amongst another cohort in a similar stage of the disease. Tröster and Woods (2007), however, claimed that cognitive impairment is more common with an earlier onset, occurring in one third of people with only mild to moderate PD.

It is known that the prevalence of cognitive impairment significantly increases with disease progression. However, the number of drivers with PD in Australia who have cognitive impairment is unknown (Amick, et al., 2007). Inability to accurately screen for cognitive impairment is of concern to road safety, since people who are affected may not be aware of it. If drivers with PD are not aware of the need to self regulate driving behaviour and/or compensate for performance alterations, the risk to road safety is increased (Amick, et al., 2007). Drivers may not seek medical advice and/or driving assessments may not be sought as needed, as the potential impacts upon driving performance are poorly understood (Betz & Fisher, 2009). Jones (2009) found that the most frequently self-identified cognitive areas affecting driving amongst people with PD were decision making, complex attention, visual search, impulse control, planning and divided attention. They also conducted a meta-

analysis, and found that these six areas have been associated with previous incidents of unsafe driving and traffic errors (Amick, et al., 2007; Innes, et al., 2009).
In a study of 150 people with PD, it was found that cognitive impairment had a significant impact upon the crash rate per miles driven, irrespective of the actual disease severity (Devos, et al., 2007). Other studies have found that drivers with PD have increased indecision at T-junctions and when changing lanes, as well as a slower information processing speed, reaction time and decision making speed (Heikkila, et al., 1997; Stolwyk, et al., 2006). The current study focuses primarily upon decision making ability, which has been identified as one of the most important contributing factors to safe driving.

### 1.3 Drivers with Parkinson's disease and road safety

In 2008, traffic collisions caused 1,402 preventable deaths in Australia (Australian Bureau of Statistics, 2008). Deaths and disabilities caused by traffic collisions result in extensive, long term, social and emotional costs to families, friends and communities (Elvik & Vaa, 2004). Traffic collisions have vast financial implications; including healthcare services, insurance premiums, property damage and clean up services (Australian Bureau of Statistics, 2008). Therefore, improving road safety through research is of high importance to save lives and prevent disabilities. Although the majority of traffic collisions are preventable, the number of collisions is actually predicted to increase substantially in the future. Escalating population density in cities, increased usage of vehicles and number of cars per household are resulting in Australian road networks becoming more complicated and demanding (Australian Bureau of Statistics, 2009). The fastest growing population of Australian drivers are aged over 70 years, as improvements in healthcare have enabled drivers, including those with PD, to retain their licences for longer (Australian Bureau of Statistics, 2004). The ageing population demographics, in combination with the increased complexity of road systems, mean that the risk of collision for drivers over 65 years is predicted to triple by 2030 (Australian Bureau of Statistics, 2004). This older population are also more likely to sustain serious injuries or death during collisions due to age-related deterioration of musculoskeletal and cardiovascular systems (Adler, et al., 2000).
Longer licence retention can be very beneficial in improving the quality of life of older Australians, since they are able to maintain independence, access to the community and preserve their self-efficacy (Radford, et al., 2004). However, older drivers must be able to compensate for their age-related deficits, since the increasing complexity of road systems place additional demands on cognitive, physical and sensory systems (Elvik & Vaa, 2004). Drivers with PD face further challenges as the PD symptoms as well as side effects of medication can interfere with driving performance. Research, both on-road and using driving simulators, has shown that drivers with PD commit more risky faults and driving offences, and have a significantly increased number of collisions per kilometre driven when compared to the average population (Devos, et al., 2007; Radford, et al., 2004). Despite the challenges faced by drivers with PD in continuing to drive, it is unethical to cancel their licences based upon diagnosis of the disease alone (Tröster & Woods, 2007). Many drivers with PD are able to overcome barriers using their extensive driving experience and knowledge of road systems or they can compensate for the declining ability through self-monitoring and self-regulation (Stolwyk, et al., 2006). For example, a person who becomes overwhelmed when driving at high speeds may change their route to avoid freeway driving (Tröster & Woods, 2007).

In Australia, like most of the developed countries, the guidelines regulating licence retainment and cancellation are based upon a system of subjective medical expert opinion (Adler, et al., 2000). There are no current national standards or requirements for how clinical driving assessments should be conducted (Innes, et al., 2009). Medical experts are often required to determine driving performance, even though the majority have not been trained in driving assessment, or actually observed their patient driving a car (Adler, et al., 2000). Specific clinical assessment batteries and criteria to renew or cancel driving licences have not been clearly defined in the Australian Assessing Fitness to Drive handbook; the combination of symptoms and/or the severity that could compromise driving ability are not defined (Cordell, et al., 2008). Therefore, the medical practitioner must make a subjective decision on the fitness to drive of their patients, even though they may not have been trained to do so (Cordell, et al., 2008). Most current methods of determining licence retainment or cancellation is through on-road driving tests and/or clinical psychometric assessments (National Road Transport Commission, 2003). On-road assessment is the gold standard. However, the process is costly and time consuming (Bedard, et al., 2010; Bryer, et al., 2006). A person who is unable to undergo a driving assessment as recommended by their medical professional is unlikely to be able to retain their licence (Anceaux, et al., 2008). The high assessment cost and need for drivers with PD to undergo annual driving reviews may contribute to the early cessation of driving (Access Economics, 2010).

The cheapest, most accessible and commonly used method for determining driving ability is through clinical assessment. Tools, such as the Timed Up and Go (measures ability to stand up, walk for 3 metres and return to the chair), Unified Parkinson's Scale and Mini Mental Status Examination (MMSE) are commonly used (Cordell, et al., 2008). However, the predictive validity of using these tools in driving assessment is frequently questioned in the literature (Anceaux, et al., 2008; Betz & Fisher, 2009; Cordell, et al., 2008; Stolwyk, et al., 2006). Radford, Lincoln and Lennox (2004) stated that an objective and reliable assessment tool to measure driving ability do not currently exist. Based upon an extensive literature review, Molnar, Marshall and Man-Son-Hing (2006) concluded that no office-based test had validated cut-off scores that correlated to on-road driving performance amongst people with dementia. Ernst and Paulus (2005) noted that it is difficult to assess risk-taking behaviours in an indoor, clinical setting without actually watching the person drive. In a double blind study using 20 people with PD and 20 age-matched controls; it was found that there was a 35% inconsistency in clinical assessment results conducted by a neurologist, compared to on-road driving assessment results provided by a driving instructor and occupational therapist (Heikkila, et al., 1997). Although these results need to be interpreted with caution due to the small sample size; it does highlight that assessment processes need to be improved. Moreover, the Heikkila el al study (1997) did suggest that visual memory, choice reaction time and information processing speed tests could potentially be used to assess fitness to drive; once more research is conducted to establish validity and reliability. Betz and Fisher (2009) suggested that further research into the detection of cognitive impairment and its potential implications for road safety is becoming more crucial in preventing fatal collisions as the population ages.

### 1.4 Impact of poor decision making ability of PD drivers on driving performance

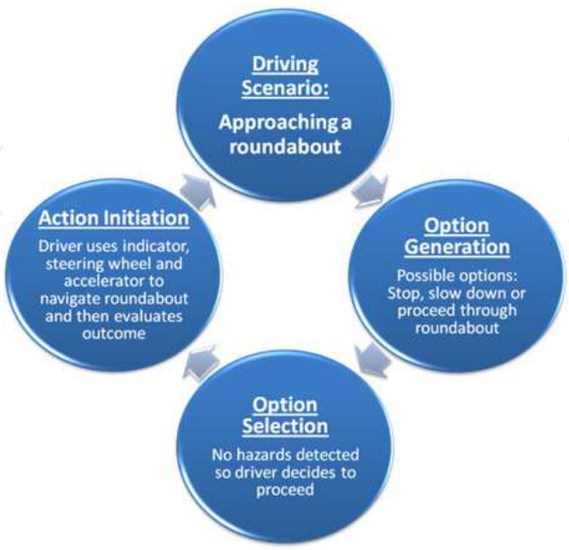
PD-related cognitive deficits are believed to occur due the inefficient neurotransmission of dopamine-dependent neural connections between the basal ganglia and other areas of the brain (Tröster & Woods, 2007). The deprivation of dopamine, caused by the damage to the

basal ganglia, can directly affect the cognitive functions that are essential to decision making ability. These include; time estimation, working memory, executive function, compulsion, perseveration, attention, motivation and information processing speed (Cools, et al., 2001). Additionally, priority given to stimuli, error prediction, action planning, learning and interest in the environment are also affected (Ernst & Paulus, 2005). Furthermore, Nieoullon (2002) stated that the reduced amount of dopamine may interfere with a person's ability to perform an activity or behaviour, as well as alter a person's ability to adapt to environmental changes. Making decisions is a high-level cognitive function that involves the caudate nucleus and ventral striatum of the basal ganglia, as well as parts of the prefrontal cortex of the brain (Ernst & Paulus, 2005). The decision making process is reliant upon the neurotransmitter dopamine to transmit information via the mesocortical and mesolimbic pathways to the involved areas of the brain (Cools, et al., 2001). Due to the complexity of the decision making process, multiple high-level cerebral functions contribute to the ability to make a decision within a set period. These include attention, information processing speed and capacity, working memory, concentration, recall memory, planning, complex reasoning and risk assessment (Busemeyer & Stout, 2002; Kalis, et al., 2008). Fatigue, stress, emotions and medication can cause the speed and accuracy of decision making ability to fluctuate (Ernst & Paulus, 2005).

The Decision Making Process Model (see Figure 2) defines three important stages to making a decision: Option Generation, Option Selection and Action Initiation (Kalis, et al., 2008). PD can affect all of the components of decision making, although the severity of deficits vary from person to person (Stolwyk, et al., 2006; Tröster & Woods, 2007). This model has been employed in research to study PD in numerous activities other than driving (Levy & Dubois, 2006). Firstly, in Option Generation the person considers the requirements of the situation and thinks of possible courses of action. Then during the Option Selection stage, the person analyses each potential course of action for probable outcomes. Factors that can influence the selection of one course of action over the alternatives include: probability of the benefits and/or risks, the person's previous experiences, emotional state, values and preferences for one course of action (Ernst & Paulus, 2005). Finally, in Action Initiation, the decision is implemented through physical actions (Kalis, et al., 2008). The person then evaluates the results of the decision to promote learning for future situations. According to Busemeyer and Stout (2002), poor decisions can be due to a failure to anticipate consequences, poor perceptual sensitivity, problems in memory storage or retrieval, inability to determine possible courses of action, fatigue, poor concentration, difficulty in learning from mistakes, and/or impulsivity.

Decision making deficits have been recognised as a key area that could influence driving competence and safety amongst people with PD (Cools, et al., 2001). Dopamine has an important role in facilitating the cognitive processes that enable a person to make a decision. However, what this functionally entails for driving is poorly understood (Arias-Carrión & Pöppel, 2007; Cools, et al., 2001). Deficits in decision making are most apparent during activities, such as driving, that require spontaneous, complex information processing and reasoning within time constraints (Tröster & Woods, 2007). The driver may have to make multiple decisions in quick succession, which place extensive demands upon cognitive processes. The driver must quickly consider all components of the situation, generate and consider options, implement the choice, evaluate the result and then start the decision making process again (Busemeyer & Stout, 2002). The driver may also have to ignore multiple distracting auditory, visual and tactile stimuli from the car's radio, air

conditioning, passengers and the visual environment (Ernst & Paulus, 2005). Medication, fatigue, other PD symptoms, co-morbid conditions and environmental distractions can also intensify the deficits experienced by drivers with PD (Tröster & Woods, 2007).




(Adapted from: Kalis, et al., 2008; Lefy & Dubois, 2006)

Fig. 2. Summary of the decision making process in driving

Decisions can be made either through conscious deliberation, for example, deciding if a parking space is large enough for the car, or through an unconscious process using previously learned behavioural patterns; for instance, automatically using the indicator when leaving a roundabout (Ernst & Paulus, 2005). PD can cause deficits in decision making ability at any of the decision making stages, and the resultant hesitancy, ambivalence or apathy may significantly impact upon road safety for the driver and other road users (Kalis, et al., 2008). As shown in Figure 2, if a driver is indecisive about whether to stop, slow down or to proceed through a roundabout, they could increase the risk of collision due to either incorrect use of signals, inappropriate speed or lane placement, sudden braking without checking review mirrors and/or impulsively increasing speed. All of these actions can directly result in a collision, especially as the other drivers may not be able to anticipate the indecisive driver's actions and react in time.

Numerous studies have identified that hesitancy and indecision contribute to a higher risk of crashing. However, the extent of the contribution is unknown (Bryer, Rapport, & Hanks, 2006; Stolwyk, et al., 2006). Drivers with PD frequently have a lack of cognitive flexibility and difficulty in shifting attention and multi-tasking, particularly when in stressful situations (Arias-Carrión & Pöppel, 2007). Drivers with PD often drive at slower speeds, have reduced reaction times and can fail to notice specific landmarks and traffic signs (Stolwyk, et al., 2006; Uc, et al., 2009). A study that surveyed 5,210 drivers with PD found that cognitive deficits are strongly associated with dangerous driving, with the most common causes of collision being indeciveness at T junctions and reduced usage of mirrors (Meindorfner, et al., 2005). A review of 42 driving studies concluded that the effect of a disease upon driving performance is difficult to determine due to numerous confounding factors. It is not currently possible to conduct an extensive randomised controlled trial into

this area, since there is not yet enough information available to control all confounding variables (Elvik & Vaa, 2004). Therefore, the study reported in this chapter was valuable in trialling alternative assessment methodologies and making recommendations for future research projects. Information from the study may also contribute to the development of a successful assessment protocol for drivers with PD to improve road safety.

## 2. Methodology

### 2.1 Purpose of study

The aim of the research was to explore the impact of impaired decision making ability upon the driving performance of people with PD. To address the aim, a quantitative, pre-post case-control study design was employed to assess participants the decision making ability of drivers with PD and healthy controls, as well as their driving performance under time pressure, were examined. The objectives of the study are: **Objective 1:** To assess the decision making ability of drivers with PD using standardised psychometric assessment tools and the E-prime computer based assessment; **Objective 2:** To investigate the relationship between the decision making ability and driving performance of people with PD; and **Objective 3:** To compare the driving performance of people with PD to the healthy control group whilst driving under a time pressure in the driving simulator.

The first objective was addressed by administering an assessment battery of clinical psychometric tests to assess the main cognitive processes that contribute to decision making ability. The assumption was that drivers with PD would have lower scores on the psychometric assessments, due to PD-related cognitive impairments, when compared with the healthy control group. The second objective was addressed by assessing the driving performance of the groups on the driving simulator. The assumption was that drivers with PD would have poorer driving performance at baseline driving (Trial One) as well as driving under time pressure (Trial Two) when compared to the healthy control group. The third objective was addressed by analysing the results from stage one and two to determine if there is a correlation between driving performance and decision making ability. The assumption was that the ability of people with PD to make correct decisions whilst driving under time pressure would be significantly lower than the control group. Ethical approval was granted by the Curtin University Human Research Ethics. Data was collected from Sept 2009 until March 2010 at the Curtin University Driving Rehabilitation Clinic.

### 2.2 Participants

Convenience sampling was used to recruit participants by displaying advertisement posters at community centres, retirement villages, shopping centres and neurologists' offices. Advertisements were also placed in community newsletters, as well as the Western Australia Parkinson's Association newsletter. Study participants were required to be community living adults, aged 50 to 80 years old with a valid driving licence. They had to be current drivers, driving at least half an hour each week. To ensure adequate binocular acuity, a score of at least 6/12 corrected vision on the Snellen Acuity Chart was required. In the experimental group, each participant's diagnosis of PD had to have been confirmed by a general practitioner or neurologist. Participants were excluded from the study if they had severe hearing impairments or inadequate comprehension of written or verbal English as judged by the researcher, or any co-morbid diagnosis that may interfere with driving ability. Participants with the following conditions were excluded from the study: dementia, severe

cognitive or physical impairment, depression and/or psychiatric conditions. Participants were withdrawn from the study immediately if they requested to do so. A reason for withdrawal was not required. Fifteen drivers with PD and 17 control group participants were recruited were contacted by phone to establish suitability to participate in the study.
To address Study Objectives 2 and 3, baseline-driving performance was established in Trial 1 and then a time constraint was imposed to create pressure upon the participants. In Trial 2, all participants were told to complete the same driving scenario 20% faster than in Trial 1. The percentage of reduction in time was based upon pilot study data. A 20% reduction represented a time that was perceived by the participants as being challenging, yet achievable within the driving assessment parameters. This time pressure forced the participants to make quicker decisions in response to the traffic conditions, without compromising on safety or breaking the road rules. Drivers with PD are more likely to experience decision making deficits whilst making complex decisions under pressure (Amick, et al., 2007). The study assumption is that drivers with PD are capable of making correct decisions; however, they require more time to do so. Important driving behaviours, such as appropriate signalling, use of mirrors and obeying the speed limit potentially could have been affected and/or forgotten as the participants concentrated upon negotiating the scenario faster. The driving performance of participants was measured using Driving Performance Score. A battery of psychometric assessment tools were administered to the participants to assess the cognitive processes that are essential to decision making ability. The cognitive processes included executive function, task switching, sustained, selected and divided attention, attention set shifting, memory, efficiency and accuracy of information processing systems, visual attention and decision making speed and accuracy. All psychometric assessment tools were time based, standardised instruments that measured speed and accuracy of response. The study assumption was that drivers with PD are capable of completing the assessments; however, they will require more time to do so. The confounding variables in the study are presented in Table 1 in next page. Measures have been taken to ensure that the data collected was valid.

### 2.3 Equipment used in the study

The following section describes the tools used for initial screening of participants, and psychometric assessments for measuring the main components of decision making in driving.

#### 2.3.1 Initial screening of participant medical and driving history

Standardised clinical assessment tools and a Medical History and Driving History Checklist were used to screen for potentially confounding factors (refer to Table 2 and Table 3 for details of assessments). All assessments were administered in a quiet, distraction free room as per the instruction manuals to ensure the reliability of data. The research assistant was trained in administering these assessments prior to commencement of the data collection.

#### 2.3.2 Psychometric assessment

Decision making ability cannot be directly measured. Instead, the main contributing components were all assessed using a battery of psychometric assessments. These components were attention set shifting, visual attention, memory, information processing speed and decision-making speed and accuracy (refer to Table 3). The psychometric

| Variable | Potential Impact | Measures taken to improve validity |
|---|---|---|
| Medication | - Side effects of medication could affect functional performance. (Radford, et al., 2004). | - Drivers with PD were assessed during periods of optimal function, to ensure that motor and non-motor fluctuations in performance did not affect results (Radford, et al., 2004). |
| Co Morbid Conditions | - Symptoms and medications for co-morbid conditions could alter functional performance (Radford et al., 2004). | - People with co morbid medical conditions that could affect driving performance were excluded from the study. Refer to Exclusion Criteria and the Screening procedure. |
| Fatigue | - Fatigue may affect driving performance especially as participants are older (Radford, et al., 2004). | - Assessment periods were held during mid morning and early afternoon and frequent rest breaks with refreshments were offered. |
| Driving Experience | - People who have been driving either longer or more frequently are likely to be better drivers (Bedard, et al., 2010). | - The Driving History Checklist was used to seek a fair distribution of driving experience across groups. All drivers must have driven at least one half hour a week to ensure the maintenance of skills. |
| Gender | - Men have a greater risk of having a fatal crash (Adler, et al., 2005). | - A fair distribution of gender between groups was sought. Statistical analysis identified the gender-related difference in performance. |
| Age | Driving performance usually decreases after the age of 60 years (Adler, et al., 2000) | - A fair distribution of ages between groups was sought. Statistical analysis identified the age-related difference in performance. |

Table 1. Confounding variables of the study

assessment battery comprised of the Symbol Digit Modalities Test (Smith, 2007), Digit Vigilance Test (Kelland & Lewis, 1996), Purdue Pegboard (Lafayette Instrument Company, 1985) and Trail Making Test – B (Corrigan & Hinkeldey, 1987).

The assessments were chosen based upon recommendations from literature to ensure high reliability, sensitivity, and/or validity of each test in assessing driving performance. For example, the Trail Making Test-B, Symbol Digit Modalities Test and Digit Vigilance are highly sensitive to detecting differences in cognitive performance (Smith, 2007). The Trail Making Test-B is one of the most frequently used tests in driving research and clinical settings, due to its high reliability and sensitivity to mild cognitive impairment (Arbuthnott & Frank, 2000; Ashendorf et al., 2008). The Symbol Digit Modalities Test was found in a study of 150 people to be the most reliable of 12 assessment tools in detecting mild cognitive impairment (Ashendorf, et al., 2008).

| Screening Tool | Purpose of Assessment Tool | Administration and justification for Use |
|---|---|---|
| Medical Checklist | - To gather demographic medical information and screen for excluding factors. | - Based on medical screening assessments according to Australian Driving regulations (National Road Transport Commission, 2003). |
| Driving History Checklist | - To gather demographic driving information and screen for excluding factors. | - Based on current Driving History assessments at the Independent Living Centre and Australian driving regulations (NRTC, 2003). |
| Snellen Acuity Chart | - A standardised measure frequently used in driving assessment to screen for binocular acuity deficits (Lotfipour, et al., 2010) | - Adequate binocular vision was assumed based upon the ability to read a series of letters on a chart placed 6 metres away. Minimum standard for on road driving is 6/12 corrected vision (NR TC, 2003). |
| Cognistat (Kiernan, Mueller, Langston, & Van Dyke, 1987) | - Brief screening tool to detect cognitive impairment Subtests of attention, constructional ability, memory, calculations, reasoning and judgement were administered. | - Economical and efficient clinical screening tool that has high sensitivity to cognitive impairment (Adler, et al., 2000) |

Table 2. Outline of Screening Tools

### 2.3.3 E-Prime computer based tool

The E-Prime software has been used in 104 research studies since 2001; including research projects into simulated situations, older adults and neurological conditions (Psychology Software Tools, 2010). The E-Prime software is capable of millisecond precision and is frequently used in research to increase the accuracy and reliability of data (Ranzini, et al., 2009). In the present study, the E-Prime computer program was set up to measure the speed and accuracy of the participants' decision making ability by administering a series of multiple choice questions (refer to Figure 3). The questions were based upon traffic situations in which drivers with PD are known to experience difficulty; such as roundabouts, traffic lights, freeway driving, city driving, over taking and right hand turns (Allen, et al., 2003; Anceaux, et al., 2008; Lee, et al., 2003). It took approximately 10 minutes to complete.

The "red", "yellow" and "green" button system (refer to Figure 3) had buttons that were large, visually distinguishable, and highly sensitive to touch, to enable people, who experienced PD-related physical symptoms to enter their decision as quickly as possible. The computer was placed in front of a blank, white wall and the researcher sat behind the participant, out of sight to prevent potential distractions. The questions were displayed in large, white writing on a black backdrop to improve readability. A black instruction screen was displayed to inform participants about how to answer the following question (refer to Figure 4).

| Psychometric Tool | Purpose and Administration | Literature support for tool validity |
|---|---|---|
| Trail Making Test B (TMT-B) (Corrigan & Hinkeldey, 1987) | - To assess executive function, visual attention and task switching (Corrigan & Hinkeldey, 1987). Participants join alternating dots of letters and numbers (1, A, 2, B etc.). | - TMT-B is suggested for older driver assessment as a score of over 180 seconds could indicate increased driving risk (Betz & Fisher, 2009). Moderate predictive ability for increased crash risk (Bedard, et al., 2010). |
| Purdue Peg Board (Lafayette Instrument Company, 1985) | - To assess bilateral gross motor movements and dexterity of the fingers, hands and arms to distinguish between the influence of physical and cognitive PD-symptoms on results. | - Range of norms for people over 65 years available. High test-retest reliability (0.82 to 0.91), moderate sensitivity and moderate predictive ability for driving (Wood, et al., 2005). Suggested for assessing impact of neurological disease upon motor function (Wood, et al., 2005). |
| Digit Vigilance Test (Kelland & Lewis, 1996) | - To assess sustained, selected and divided attention, and information processing speed and accuracy. Participants scan rows of single digit numbers and circle all of the number sixes. | - High test-retest reliability and has been validated as a measure of sustained attention (Kelland & Lewis, 1996).<br>Determines if participants were able to remember and attend to important information whilst disregarding excess stimuli (Radford, et al., 2004). |
| Symbol Digit Modalities Test (Smith, 2007) | - To measure the efficiency and accuracy of information processing systems. Participants had to convert geometric shapes into numbers as quickly as possible. | - Substitution tasks are highly sensitive to detecting cerebral dysfunction (Wood, et al., 2005). Norms provided for age and education levels. High test-retest reliability (0.80). Moderate predictive ability for driving ability (Wood, et al., 2005) |
| E-Prime Computer Based Assessment (Psychology Software Tools, 2010) | To assess decision making accuracy and response time<br>- Multiple-choice questions based upon photographs of different driving scenarios. | - Software is capable of capturing the responses of participants with millisecond precision (Ranzini, et al., 2009). Standardised video instructions used for to improve inter-rater and intra-rater reliability. |

Table 3. Outline of the Psychometric Assessment Tools




Fig. 3. The setup of the E-Prime Assessment tool

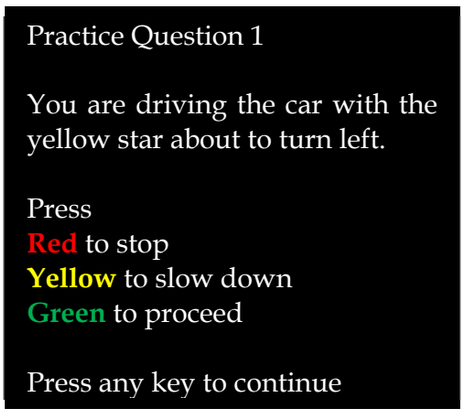



Fig. 4. E-Prime Instruction Screen



Fig. 5. The E-Prime Assessment Tool; displaying an example of a question

In each photograph there was a car labelled with a bright yellow star (refer to Figure 5). Participants were instructed to assume that he or she was the driver of the car with the yellow star and give the most appropriate response for each scenario. The participant had to decide whether they would 'stop', 'slow down' or 'proceed' based upon their interpretation of the hazards as shown in the photograph. Participants responded using one of the three

buttons. The accuracy of answers and response time was automatically recorded by the E-Prime software to determine decision making ability.

### 2.3.4 Driving simulator in curtin driving rehabilitation clinic

A fixed-base, Systems Technology Incorporated (STI) driving simulator was used to assess driving performance in this study (Lee, et al., 2003). Driving simulators are frequently used in research and clinical practice to assess driving ability, since risk of injury and property damage is eliminated (Bedard, et al., 2010). The STISIM driving simulator enables the development of highly controlled and regulated traffic scenarios (Allen, et al., 2003). The STISIM simulator technology has been used in 61 different studies, whilst the STISIM simulator driving technology in particular has been used in at least 24 studies in the past eight years (Systems Techonology Inc, 2010). Low cost, fixed base driving simulators have been used in research on older drivers and on the effect of fatigue, drugs, cognitive impairment, Alzheimer's disease, PD, traumatic brain injury and numerous other conditions upon driving performance (Bedard, et al., 2010; Lee, et al., 2003). Driving simulators are becoming more affordable options; especially as on-road assessment costs are becoming more prohibitive due to the increasing fuel, car purchase and maintenance costs and higher insurance premiums (Bedard, et al., 2010).



Fig. 6. The Curtin University STISIM Driving Simulator

Simulators are capable of distinguishing between safe and unsafe drivers (De Winter, et al., 2008; Lee, et al., 2003). Numerous studies have found high transferability of simulator-based behaviours to on-road driving behaviours (De Winter, et al., 2008; Lee, et al., 2003). Factor and Weiner (2002) found that driving simulators have a greater accuracy in predicting driving ability than the clinical psychometric assessments currently used by medical practitioners. High inter-rater and intra-rater reliability (correlation coefficients were 0.87 and 0.83 respectively) were recently established by Bedard and colleagues (2010). They used the simulator-recorded data and data manually recorded by a laboratory assistant in a similar STISIM simulator. The validity of the driving simulator used in this study has been established for assessing older adults (Lee, et al., 2003). A photograph of a participant being assessed on the Curtin University STISIM Driving Simulator is shown in Fig. 6.

### 2.3.5 Development of the STISIM driving scenario

Two driving scenarios were specially designed for the present study. They were based upon the Western Australian licensing standards, in combination with recommendations from

driving simulator literature (Allen, et al., 2003; Factor & Weiner, 2002; Lee, et al., 2003; National Road Transport Commission, 2003). In the present study, the roadway geometry and intersections, position of traffic signals and markings, weather conditions, the responsiveness of vehicle controls, location of other vehicles and road users were all programmed to target decision making ability. The scenarios included small town, city and country driving, simple and complex intersections, curved roads, simulated emergency braking, varied speed control and visually obscured intersections. Auditory instructions were included in the simulator programming to ensure that all of the information and instructions were consistent throughout data collection.

To investigate the impact of PD-related decision making deficits upon driving performance, the scenario in this study was designed to specially assess hazard detection, risk assessment, impulsiveness and decision making ability (Bedard, et al., 2010; Elvik & Vaa, 2004). Traffic situations that are known to be affected by PD, such as driving at high speeds, turning corners, overtaking, merging and complex city intersections were included (Stolwyk, et al., 2006; Radford, et al., 2006). For example, during the scenario, a recorded verbal instruction told each participant to overtake three slow moving trucks whilst avoiding oncoming traffic. A similar process was used in a study by Amick et al., (2007) as they researched cognitive indicators of poor driving performance of drivers with PD. Driving Performance Assessment Guidelines was tabulated in Table 4.

### 2.4 Data analysis

Data was analysed using the Statistical Package for Social Sciences (SPSS) (SPSS Inc. 2009). Demographic information of participants was presented using descriptive statistics. The difference in total run time and driving performance score between groups was analysed using t-tests; whereas a Chi squared test and Fisher's Exact test was used to analyse ordinal variables, such as gender and number of collisions and infringements. A stepwise Multiple Linear Regression Model was used to analyse the driving performance and E-Prime scores; the driving performance score was the dependent variable and E-Prime (correct answers, time taken and participant group) were the independent variables. The psychometric assessments and the components of the Driving Performance Score were analysed using the non-parametric Wilcoxon 2-sample test. A repeated measure regression analysis was performed using the driving score as a dependent variable and the results of the psychometric assessments, simulator trial run number and group identifier (drivers with PD or control group) as independent variables. The least significant variables were then removed, one at a time, until the p-value associated with each of the remaining variables was less than 0.05. Prior to the analysis, normality of data and the assumptions of the statistical tests were checked to ensure that there were no violations.

## 3. Study results

### 3.1 Participant demographics

Seventeen people in the control group and 11 drivers with PD were assessed and their demographic data was tabulated in Table 5. In exploring the characteristics of the participants, it was identified that the number of years of driving experience was different between the comparison groups ($p=0.042$). The drivers with PD group had driven on average 7 years and 8 months longer than the control group. The participants' age, gender, employment status and education level were found to be not significantly different between groups.

| Assessment Component | Definition of Required Behaviour/Skill | Assessment Frequency and Scoring Procedure |
|---|---|---|
| Frequency of Appropriate Use of Mirrors | - Driver checked left and right mirrors immediately before slowing down, turning or diverging. | - Assessed at 25 locations/events. One point deducted for each omission per mirror |
| Smooth Manoeuvring around Obstacles | - Driver smoothly manoeuvres around obstacles and maintains a safety buffer around vehicle. | - Assessed at nine locations/events. Up to three points deducted depending on severity of error |
| Frequency of Appropriate Stopping Distance | - Driver stops at an appropriate distance from traffic lights, stop signs and obstacles. | - Assessed at 20 locations/events. Up to four points deducted depending on severity of error |
| Maintains Appropriate Vehicle Speed | - Driver maintained vehicle within 9kms of the appropriate speed limit. | - Assessed at 23 locations. Points deducted for excess speed as per national guidelines. |
| Maintains Correct Lane Position | - Driver stays within the lane markers or to the left on unmarked roads. | - Number of deviations recorded by stimulator. One point deducted for each instance. |
| Maintains Control of Vehicle on Turns | - Driver kept vehicle stable and adjusted speed as required around turns and on winding roads | - Number of deviations recorded by simulator. One point deducted for each time. |
| Appropriate Behaviours to Avoid Hazards | - Driver had sufficient room to react, was alert and aware of environment and in control of vehicle | - Number of sudden braking incidents recorded by stimulator. One point deducted for each omission |
| Appropriate Use of Indicators | - Driver appropriately used indicators to give warning about future diverging movements. | - Assessed at 22 locations/tasks. One point deducted for each omission. |
| Demonstrates Caution during Manoeuvres | - Driver did not overtake when unsafe, allowed adequate room and stopped at yellow traffic lights. | - Assessed at 27 locations/tasks. Up to three points deducted depending on severity of error |
| Qualitative Feedback (Bedard, et al., 2010; Elvik & Vaa, 2004) | - Participants comments were recorded verbatim. Clinical observations regarding participant's affect were recorded. | - Information gathered to compliment quantitative data. No points were deducted for clinical observations and feedback |

(Bedard, et al., 2010; Bryer, et al., 2006; Elvik & Vaa, 2004; National Road Transport Commission, 2003).

Table 4. Driving Performance Assessment Guidelines

| Variable | Drivers with PD n=11 Mean (SD) | Control n=17 Mean (SD) | p-value |
|---|---|---|---|
| Age | 68.2 (5.3) | 65.6 (8.8) | 0.427# |
| Gender | | | |
| – Female | 6 (55%)ˇ | 7 (41%)ˇ | 0.489^ |
| Weekly hours driving | | | |
| – Minimum | 8.0 (8.5) | 13.7 (9.9) | 0.162# |
| – Maximum | 9 (8.6) | 14.7 (11.3) | 0.204# |
| Years of Driving Experience | 50.6 (5.5) | 42.9 (9.2) | 0.042* |
| Number of Collisions in last 2 years | 0 | 3 (28%) | 0.526+ |
| Number of Infringements in last 2 years | 0 | 2 (12%) | 0.515+ |
| Education Level | | | - |
| – Tertiary Study | 4 (36%)ˇ | 8 (47%)ˇ | - |
| – Year 12 High School | 4 (36%)ˇ | 6 (35%)ˇ | - |
| – No answer | 3 (28%)ˇ | 3 (18%)ˇ | |
| Disease Symptoms | | | - |
| – Tremors in legs | 3 (28%)ˇ | - | - |
| – Tremors in arms | 7 (63%)ˇ | - | - |
| – Mild Rigidity | 4 (36%)ˇ | - | - |
| – Moderate Rigidity | 4 (36%)ˇ | - | - |
| – Severe Rigidity | 0 | - | - |
| – Mild Fatigue | 2 (18%)ˇ | 3 (18%)ˇ | - |
| – Moderate Fatigue | 7 (63%)ˇ | 3 (18%)ˇ | - |
| – Severe Fatigue | 0 | 0 | |

^ Chi squared test; # T-test; + Fisher's Exact test; *Results were statistically significant ($p<0.05$) and ˇ Categorical frequency (percentage)

Table 5. Results of Participant Demographic Data

The drivers with PD had on average a diagnosis of PD for approximately 8 years and 4 months. Medications that were prescribed to the participants with PD included: Sinemet, Madopar, Cabaser, Sifrol and Selgene. Some participants with PD reported experiencing tremors in arms and legs as well as mild to moderate rigidity and fatigue (refer to Table 5). Six of the control participants reported experiencing mild to moderate fatigue, which was not related to PD. All participants with PD reported they required only minimal assistance to complete self-care activities, whilst none of the participants in the control group required any assistance.

### 3.2 Psychometric assessment results

The results of four standardised, psychometric assessments and the E-Prime Assessment Tool are shown in Table 6. The only psychometric assessment tool that detected a difference between the groups was the Purdue Pegboard Both Hands subtest and Overall Score. These results indicate that there may be a difference in the speed and dexterity of upper limb

movements between the two groups. There were no statistical differences between groups on the E-Prime Test, Symbol Digit Modalities Test, Digit Vigilance Test and Trail Making Test B.

| Psychometric Test | Drivers with PD (n= 11) ** Mean (SD) | Control Group (n=15)** Mean (SD) | Wilcoxon Two-Sample Test) p-value |
|---|---|---|---|
| E-prime | | | |
| Correct Answers | 12.6 (3.5) | 12.7 (3.1) | 0.96 |
| Response Time/seconds | 126,686 (45,463) | 91,482 (34,344) | 0.42 |
| Symbol Digit Modalities Test | 44.33 (5.63) | 49.13 (8.46) | 0.18 |
| Digit Vigilance Test | | | |
| Page One | 3.41 (0.63) | 3.37 (0.69) | 0.64 |
| Page Two | 3.57 (0.71) | 3.46 (0.64) | 0.87 |
| Trail Making Test B | 1.27 (0.65) | 1.05 (0.45) | 0.84 |
| Purdue Pegboard | | | |
| Right Hand | 11.75 (2.66) | 13.71 (2.02) | 0.20 |
| Left Hand | 11.25 (2.43) | 12.79 (1.67) | 0.17 |
| Both Hands | 16.25 (5.18) | 21.50 (3.72) | 0.04* |
| Assembly Task | 12.88 (4.29) | 17.43 (4.11) | 0.07 |
| Overall Score | 39.25 (9.63) | 48.00 (5.49) | 0.06 |

*Results were statistically significant ($p<0.05$)
** 8 drivers with PD and 13 control group participants were assessed using the E-Prime Assessment.

Table 6. Participant Psychometric Assessment Results

### 3.3 Driving simulator results

Two participants, one control and one driver with PD requested additional practice in using the simulator. All other participants began the assessment trials immediately following the practice session. During the assessment process, three drivers with PD and four control participants experienced simulator-induced motion sickness and withdrew. Their partial data was included in the data analyse where appropriate. An Independent t-test was used to determine if there was a difference between each group on the Driving Performance Score and the Scenario Completion Time for each trial. The results are shown in Table 7. The parametric t-test was found to be appropriate for analysing these results as the pre-post nature of assessment doubled the data entries available for analysis; fulfilling the sample size requirements (Hedges, 2009). Of note is that the difference between scenario completion times for Trial 2 had a p-value of 0.014 (refer to Table 7).

This however does not represent a difference between groups as the baseline performance in Trial 1 was dissimilar for each group and this disparity affects the results of Trial 2. The results shown in Table 7 are displayed in two box-and-whisker plots. Figure 7 represents the

change in Driving Performance Score between trials for both groups, whilst Figure 8 shows the change in Scenario Completion Time for each trial.

| Variable | Drivers with PD (n=8) Mean (SD) | Control Group (n=13) Mean (SD) | Results p-value |
|---|---|---|---|
| Driving Performance Score | | | |
| Trial 1 | 82.7 (6.0) | 76.5 (22.4) | 0.36 |
| Trial 2 | 59.2 (17.9) | 67.4 (27.3) | 0.47 |
| Between Group Comparison | -23.5 (19.1) | - 9.2 (24.4) | 0.17 |
| Comparison between Trials | | | |
| - Drivers with PD | | | 0.01*# |
| | | | 0.02*^ |
| - Control group | | | 0.20# |
| | | | 0.16^ |
| Scenario Completion Time (seconds) | | | |
| Trial 1 | 864.8 (172) | 782 (137) | 0.21 |
| Trial 2 | 776 (110) | 674 (64) | 0.02* |
| Between Group Comparison | -88.6 (73.0) | -107.5 (103.8) | 0.66 |
| Comparison between Trials | | | |
| - Drivers with PD | | | 0.01*# |
| | | | 0.01^ |
| - Control group | | | 0.01*# |
| | | | 0.01^ |

* Results are statistically significant ($p < 0.05$)
^ Wilcoxon Two-sample Signed Rank Test
# Paired T-Test

Table 7. Driving Performance and Scenario Completion Time for Trial One and Two

### 3.3.1 Comparison between the driving performance of the groups

The Driving Performance Scores of both groups decreased in Trial 2. However, the extent of this decline was significantly greater for the drivers with PD (t-test p=0.01). These results were confirmed by Wilcoxon test (p=0.03) (refer to Table 7). Although the driving performance of the driver with PD was lower under time pressure, the driving performance was not unsafe or dangerous.

The control group had a greater variance in Driving Performance Scores compared with the drivers with PD in both trials, as shown by Figure 7. When under a time pressure, the variance in Driving Performance Scores of the drivers with PD increased.

### 3.3.2 Group comparison of scenario completion time

Figure 8 shows the difference within each group for the Scenario Completion Time for trial one and trial two. All participants in both groups, except one control participant, completed the second trial faster as required. In trial one, there were four outliers in the control group as shown by the dots in Figure 8. Both groups were able to significantly decrease their Scenario Completion Time; however the control group was able to decrease their score to a greater extent.

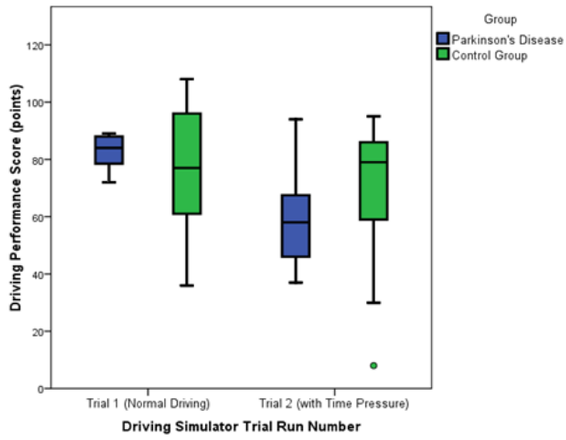



Fig. 7. Change in Driving Performance due to Time Pressure

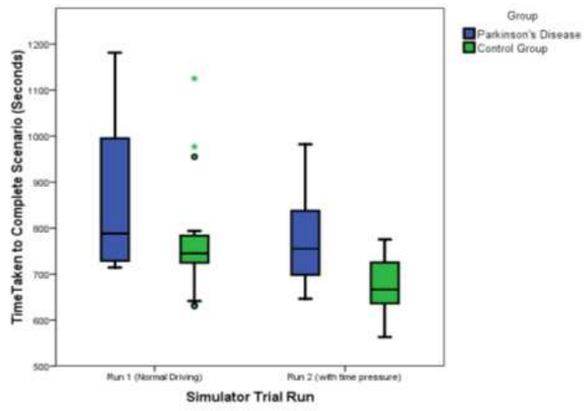



Fig. 8. Change in Scenario Completion Time for Trial One and Two

### 3.3.3 Group comparison of driving performance score components

As outlined in previous section, the Driving Performance Score comprised of 10 components representing important driving behaviours. Table 8 shows that in trial one, the drivers with PD had a low frequency of appropriate mirror use ($p=0.014$) and had more difficulty in maintaining the vehicle in a correct lane position ($p=0.02$). When under pressure, the drivers with PD continued to demonstrate a low frequency of appropriate mirror use ($p=0.012$) and they were less likely to stop the vehicle an appropriate distance from obstacles ($p=0.02$). The other components of driving were the same between groups (refer to Table 8).

### 3.4 Impact of decision making ability upon driving performance

To explore the relationship between decision making ability and driving performance, quantitative data and clinical observations that were gathered during Stage 1 and 2 of the study were analysed. A random effects regression model was adopted to analyse the results using the Driving Score as a dependent variable and the Psychometric Assessment Tests, Trial Run Number and group identifier (drivers with PD or control group) as the independent variables. All independent variables were originally included in the analysis,

| Variable | Drivers with PD Mean Score n=8 Mean(SD) | Control Mean Score n=13 Mean (SD) | (Wilcoxon Two-Sample Test) p-value |
|---|---|---|---|
| Frequency of Appropriate Use of Mirrors | | | |
| Run 1 | 8.50 (2.67) | 4.38 (3.43) | 0.014* |
| Run 2 | 12.38 (5.95) | 5.46 (3.02) | 0.012* |
| Maintains Appropriate Vehicle Speed | | | |
| Run 1 | 6.25 (6.54) | 8.08 (9.23) | 1.00 |
| Run 2 | 7.38 (6.50) | 12.31 (9.07) | 0.31 |
| Demonstrates Caution during Manoeuvres | | | |
| Run 1 | 6.00 (2.98) | 6.77 (3.98) | 0.47 |
| Run 2 | 7.00 (3.30) | 7.46 (4.52) | 0.91 |
| Frequency of Appropriate Stopping Distance | | | |
| Run 1 | 4.50 (2.73) | 4.00 (3.87) | 0.43 |
| Run 2 | 5.13 (4.36) | 1.77 (2.35) | 0.02* |
| Smooth Manoeuvring around Obstacles | | | |
| Run 1 | 3.50 (2.78) | 3.46 (2.22) | 1.00 |
| Run 2 | 6.38 (2.56) | 5.00 (2.24) | 0.25 |
| Maintains Correct Lane Position | | | |
| Run 1 | 8.13 (3.27) | 14.23 (6.00) | 0.02* |
| Run 2 | 14.50 (3.59) | 13.38(6.78) | 1.00 |
| Maintains Control of Vehicle on Turns and Winding Roads | | | |
| Run 1 | 1.75 (2.25) | 2.54 (2.30) | 0.44 |
| Run 2 | 3.38 (3.74) | 3.46 (3.18) | 0.83 |
| Appropriate Behaviours to Avoid Hazards | | | |
| Run 1 | 1.75 (2.38) | 1.08 (1.89) | 0.39 |
| Run 2 | 2.86 (3.67) | 1.54 (2.07) | 0.57 |
| Appropriate Use of Indicators | | | |
| Run 1 | 4.63 (1.77) | 6.38 (3.33) | 0.15 |
| Run 2 | 9.63 (3.96) | 7.92 (5.20) | 0.46 |
| Number of Collisions | | | |
| Run 1 | 1.50 (0.53) | 1.31 (1.03) | 0.79 |
| Run 2 | 1.25 (0.71) | 0.92 (0.86) | 0.41 |

* Results are statistically significant ($p < 0.05$)
Note: a higher score indicates poorer performance

Table 8. Analysis of Driving Performance Score Components

and then the least significant variables were excluded, one at a time, until the p-value associated with each remaining variable was less than 0.05 (refer to Table 9).

The independent variables that were found to be statistically significant were the Driving Simulator Trial Run Number, Purdue Pegboard Both Hands Score and Digit Vigilance Test Page 1 and Page 2. Confidence Intervals (set at 95%) show the reliability of the results by providing a range of scores that the true answer lies within (Hedges, 2009). As shown by the wide confidence intervals in Table 9, the reliability of these results was not convincing. A correlation between the psychometric assessment tools to driving performance therefore

cannot be assumed. Due to the small sample size, it would be misleading to perform individual parametric analysis for each variable.

| Variable | Least Squares Mean | Regression coefficient | 95% Confidence Interval | p-value |
|---|---|---|---|---|
| Group | | | | |
| - Control | 76.2 | 13.0 | -3.4 to 29.3 | 0.114 |
| - Drivers with PD | 63.3 | 0.0 | | |
| Trial Run Number | | | | |
| - 1 | 76.8 | 14.2 | 3.2 to 25.2 | 0.014* |
| - 2 | 62.6 | 0.0 | | |
| Purdue Pegboard Both Hands test | | | | |
| DVT Page1 | | | | |
| DVT Page2 | | -1.8 | -3.5 to -0.1 | 0.049* |
| | | -27.4 | -51.1 to -3.8 | 0.025* |
| | | 30.2 | 7.5 to 52.9 | 0.012* |

*Results were statistically significant ($p<0.05$)

Table 9. Multivariable Analysis of Driving Performance Score to Psychometric Assessment Results

### 3.5 Motion sickness

Three drivers with PD and four control participants experienced symptoms of motion sickness and withdrew from the study. Symptoms included mild dizziness, sweating, nausea and vomiting. The two participants who had requested additional driving simulator practice were amongst the participants who experienced motion sickness.

In all cases, the researcher ceased participation in the study as soon as mild symptoms of motion sickness were experienced. All participants except one driver with PD, recovered within half an hour without residual signs and symptoms of motion sickness. The exception was contacted the following day by the researcher, and reported no residual signs or symptoms.

## 4. Discussion

### 4.1 Participant demographics

Eight drivers with PD and 13 control participants were successfully assessed. The volunteer response rate was lower than anticipated. The recruitment process could have been affected by the stated reluctance of medical practitioners to refer clients due to potential legal implications. Legislation for the Compulsory Reporting of Medical Conditions came into effect in Western Australia only one year prior to the commencement of the study, which may have influenced the willingness of drivers with PD to volunteer. It was intended to match participants by gender, driving exposure per week and age, since these factors were identified

by previous studies as having the potential to influence results (Bedard, et al., 2010). Although perfect matching of participants would have been ideal; age, gender and driving exposure per week were not found not to be significantly different between groups. These results concur with a Queensland study using 25 drivers with PD and 21 controls, which also found that age and gender did not appear to affect the results (Wood, et al., 2005).
The only difference between the groups was the number of 'Years of Driving Experience' as the drivers with PD had more experience. This difference may have potentially influenced the results in favour of the drivers with PD having an improved performance, compared with the control group. However, both groups had been driving for over 43 years and there was found to be no difference in the current exposure of the groups to driving. Therefore, the number of years of driving experience may have had a minimal or no impact upon the driving performance results. Elvik and Vaa (2004) investigated 42 different driving studies and found that the years of driving experience was not matched between study cohorts, implying that it is not common practice to do so.

### 4.2 Psychometric data

In the literature review, it was discussed that decision-making is a complicated process involving many areas of the brain. Dopamine plays an extensive role in enabling these areas to interact and allow a person to make accurate and timely decisions (Ernst & Paulus, 2005). Based upon the prevalence rates of cognitive impairment as discussed; between two and five of the 11 drivers with PD in this study may have had cognitive deficits (Adler, et al., 2000; Factor & Weiner, 2002). If this assumption holds, it was expected that PD-related cognitive deficits would cause drivers with PD to score lower on all of the psychometric assessment tools. The psychometric results however, indicated that there was no difference between the groups upon these decision making components. This may have been due to an inability to detect a difference between groups due to small sample size.
It is possible that a self-selection bias affected the results in favour of the drivers with PD sample performing better than the general population of people with PD. Anceaux et al. (2008) claimed that it is likely that only drivers, who are confident in their ability, tend to volunteer to undergo non-compulsory assessment for research purposes. Participants in the present study were volunteers, more confident drivers, are likely to have influenced the better result of the present study. Results from the Cognistat screening concur with this observation, further supported by the fact that the screening process did not exclude any potential participants due to severe cognitive deficits. Convenience sampling was chosen to recruit participants since a more stringent sampling process would not have been achievable within the time and budget constraints of the study, particularly for recruiting the PD participants (Anceaux, et al., 2008; Elvik & Vaa, 2004). Selection sampling bias due to either snowball or convenience sampling methods is a frequently identified issue in driving studies. Other driving studies, both on-road and using simulators, frequently experience difficulty in assessing large sample sizes due to high costs, the necessity of the participant travelling to the assessment area and high dropout rates (Elvik & Vaa, 2004; Innes, et al., 2009; Kulisevsky & Pagonabarraga, 2009).
A significant difference was found between the groups on the Purdue Pegboard subtest of Both Hand for coordination and speed of bilateral hand movements. The multivariable analysis of driving performance to psychometric assessment results also suggests that the 'Both Hand' subtest may be linked to driving performance. The results reflect findings from an on-road study with 25 PD patients and 21 age matched controls (Wood, et al., 2005).

However, when interpreting the results of the present study, caution should be used due to the wide confidence intervals. Additionally, Bonferroni's correction principle for multiple testing needs to be considered, as the other results, including the overall score on the Purdue Pegboard, were not different. Therefore, the significant results on the Both Hands subtest may be due to random effect and not due to the physical symptoms of PD. It is therefore uncertain if motor performance affected the psychometric assessment results. All of the psychometric tests required physical input of data through pushing a button or writing the answer, which required a physical motor movement. It is therefore worth investigating the validity of the Oral Symbol Digit Modalities test, as well as other motor free tests, on driving performance; especially as the written versions of these assessments are routinely used to assess drivers with PD.

### 4.3 Driving simulator data

#### 4.3.1 Length of simulator practice time

As previously mentioned, two participants requested additional practice in using the driving simulator. It was noted that both of these participants later experienced motion sickness and withdrew from the study. Kennedy and Fowlkes (2000) found that increased exposure to simulated environments might increase the rate of motion sickness-related participant dropouts. Although this study cannot comment upon this phenomenon, additional research into a possible correlation of exposure time to motion sickness would be useful to provide guidelines for simulator scenario design, especially for older adults or people with PD.

#### 4.3.2 Baseline driving performance

Drivers with PD had a higher mean driving performance than the control group at baseline driving. However this was not statistically different. As shown in Figure 7, all of the scores of the drivers with PD group fell within the interquartile range of the control group. This means that groups cannot be differentiated based upon overall driving performance scores alone. There was also no statistical difference in time to complete trial one; showing that baseline time of the groups was the same. The sub sections of the Driving Performance Score that varied significantly between groups were "Frequency of Appropriate Use of Mirrors" and "Driver Maintains Correct Lane Position". The present study results are similar to the findings of numerous other studies, both on-road and using simulators, that claim that drivers with PD have more errors in these particular aspects of driving (Radford, et al., 2004; Uc, et al., 2009; Uitti, 2009). The present study suggests that although the drivers with PD had a lower driving performance score; this does not necessarily mean that they are 'dangerous' drivers. Similar findings were reported by Uc et al. (2009). Although the 84 drivers with PD in their study committed more lane placement errors, they were still found to be safe drivers overall. Numerous other studies also claim that drivers with PD can be safe drivers (Bryer, et al., 2006; Radford, et al., 2004). The results of the other studies, as with the present study, may have been influenced by self-selection bias as these studies also used convenience sampling and had a small sample size. Therefore, it is possible that people with PD may be safe drivers and so licences should not be cancelled based purely upon having a diagnosis of PD.

#### 4.3.3 Driving with time pressure

When a time pressure was implemented, the median driving performance of both groups decreased; with the drivers with PD experiencing a significant decrease in performance.

The median driving performance of the drivers with PD declined more than the control group, but none of the drivers with PD were found to be unsafe drivers. This indicates that when drivers with PD are under time pressure, they may not be able to compensate for the additional task demands as well as healthy drivers. As previously mentioned, self-selection bias may have affected the results. The drivers with PD in the study may be better or more confident drivers, suggesting that the difference between groups may be more substantial if comparing a more representative sample of drivers with PD to the control group. Findings support the results found by four other studies into PD (Devos, et al., 2007; Factor & Weiner, 2002; Radford, et al., 2004). These results should, however be taken with caution due to the possibility of self-selection bias influencing results. Both groups were able to decrease their individual Scenario Completion Time significantly when instructed to do so in trial two. In addition, it was found that the control group had a significantly greater decrease in driving completion time, compared with the drivers with PD. The difference in Scenario Completion Time does not mean that the drivers with PD are worse drivers. However, it is an interesting trend that has been noticed by other researchers. For example, an on-road study with 77 drivers with PD also found that drivers with PD were slower in completing the route than the control group (Uc, et al., 2009). Reasons for this trend and potential implications for on-road driving performance cannot be established based upon the results of the present study. The reason for the difference in time to complete the trial cannot be ascertained with complete certainty. It is possible that the drivers with PD were unable to increase driving speed whilst maintaining safe driving performance, due to either decision making deficits or other factors. Alternatively, the results could demonstrate that drivers with PD were more cautious and aware of their limitations; making them unwilling to take risks. This information confirmed the assertions made by the drivers with PD about their perception of driving performance since the onset of their PD symptoms. The observation that drivers with PD are more cautious in their driving was also concluded by numerous other studies (Adler, et al., 2000; Devos, et al., 2007). Whether behaviours undertaken by drivers with PD to self-regulate their driving are successful in maintaining safe driving performance is an important area for future research. The results indicate that drivers with PD may be capable of driving safely; showing that research projects such as this study are important in preventing capable drivers from having their licence cancelled, purely due to a diagnosis of PD. The finding that drivers with PD may be safe drivers is supported by other studies into PD and driving (Bryer, et al., 2006; Radford, et al., 2004).

### 4.4 Methodological considerations and limitations

#### 4.4.1 Reliable protocol

The reliability of the study was improved by using instruction videos, the driving simulator and standardised psychometric assessment tools. Although filming the videos and constructing an appropriate driving scenario were time consuming, these tools increased the repeatability of the study, reduced risk of inter-rater error and can enable the protocol to be generalised to clinical settings in future (Bedard, et al., 2010). Additionally, if this research project were to be repeated on a larger scale, the setting up of the assessment process and training of another researcher could be quickly performed with ease.

#### 4.4.2 Learning effect

It is possible that a learning effect influenced the results, as the participants would have been more familiar with the driving simulator and the scenario during the second trial. However,

this learning effect would have affected participants in both groups equally. Participants were not aware beforehand that they would undergo assessment on the same scenario twice and therefore would not have actively tried to memorise events and hazards during the first trial.

### 4.4.3 Motion sickness

Motion sickness is a common problem integral in driving simulator assessment (Kulisevsky & Pagonabarraga, 2009). Although the simulator presents a visual appearance of movement, the vestibular and proprioceptive systems do not detect presence of movement. The inconsistencies in sensory information may trigger feelings of nausea, dizziness or elevated temperature. This occurs more commonly in more experienced drivers and in people who have not regularly played computer and video games (Kulisevsky & Pagonabarraga, 2009). The drop out due to motion sickness experienced in this study (25%) was within the range reported by other studies using driving simulators, from 9% (Lee, et al., 2003) to 57% (Kennedy & Fowlkes, 2000), with older drivers being more susceptible to motion sickness. Kulisevsky and Pagonabarraga (2009) found that participants who experienced motion sickness in simulated driving did not have a reduced performance during on-road assessment and suggested that incidence of motion sickness is related to factors other than driving ability.

Potential reasons for the increased rate of motion sickness may include the larger size of the main simulator screen, the addition of side screens, the increased period of exposure and complexity of the driving scenario. The driving scenario in the present study included, right hand turns, driving at high speeds, winding roads, over taking and complex intersections, which were not used in the previous studies (Cordell, et al., 2008; Lee, et al., 2003). These particular elements are known to increase the risk of motion sickness; however, they are also highlighted as driving situations that are known to be challenging for drivers with PD (Kennedy & Fowlkes, 2000). Bedard and colleagues recommended that drivers should be assessed in challenging situations to ensure the detection of poor driving performance. The side screens are smaller than the main screen and consequently, the scenario images do not match up with complete accuracy in real life driving. This discrepancy in scenario images has been found in other studies to increase rates of motion sickness (Kennedy & Fowlkes, 2000). However, Kennedy and Fowlkes (2000) concluded that motion sickness occurs even on very expensive simulators with motion platforms and so purchasing a more expensive simulator will not necessarily be sufficient to address this issue.

Length of exposure to the simulator has been found to increase the risk of motion sickness, particularly among older adults and people with cognitive impairments (Kennedy & Fowlkes, 2000). Good ventilation, low lighting, herbal ginger tea and/or ginger supplements and a gradual introduction to the simulator over a three-day period can also assist to reduce the risk of motion sickness (Kennedy & Fowlkes, 2000).

## 4.5 Recommendations for future research

It is important to continue to research the cognitive deficits of drivers with PD; particularly decision making ability, as both the complexity of traffic situations, and the prevalence of PD increases (Uitti, 2009). Duplicating study designs of research projects investigating cognitive deficits amongst people with dementia may assist in improving research protocols for drivers with PD (Elvik & Vaa, 2004). A repeat of this study using a larger sample size and including drivers with PD recruited from driving assessment centres is recommended to answer the research question. When using a driving simulator to assess drivers with PD, the researcher needs to consider the implications of potential motion sickness when planning the research methodology.

Elvik and Vaa (2004) suggest that older drivers could be disadvantaged during driving assessment, since their last assessment may be as long as 50 years previously. The stress and anxiety of assessment could potentially affect driving performance, meaning that the assessment results may not represent actual ability (Elvik & Vaa, 2004). In the present study, the average time since participants had had a driving assessment varied from one to 61 years, with 35 years being the average. Participants in the present study commented that having to undergo driving assessment was stressful. As previously discussed, regular on-road assessment is impractical due to long waiting periods and high costs. There is currently no funding available for drivers with PD to undergo neither driving assessment nor driving training. Therefore, the driving simulator could potentially be used as a low cost method to assist drivers with PD to adapt to the assessment process, or to screen for people who may need an on-road review assessment of driving (Lee, et al., 2003).

### 4.6 Conclusions

This study aimed to explore the impact of impaired decision making ability upon the driving performance of people with PD. There was no difference between the decision making abilities of the groups as measured on the psychometric assessment tools. At normal baseline driving, the drivers with PD used their side mirrors less frequently, had poorer lane placement and took longer to complete the route.

When instructed to finish the scenario faster, both groups were able to have a significant reduction in the scenario completion time. The time pressure also caused a significant reduction in the driving performance scores of the drivers with PD, particularly in their stopping distance from obstacles. However, both groups were able to navigate the driving scenario safely under a time pressure. It is not possible to determine if the difference in completion time was due to the drivers with PD being unable to complete the route faster, or being unwilling to do as they self-regulated their driving. It is important to note, that although there was a difference in driving performance, the drivers with PD were not found to be dangerous or unsafe drivers. As the psychometric assessment results of the groups were the same, the impact of decision making ability upon driving performance cannot be determined at this stage. Information from the chapter is valuable in providing recommendations for further research projects into driving, Parkinson's disease and simulator use.

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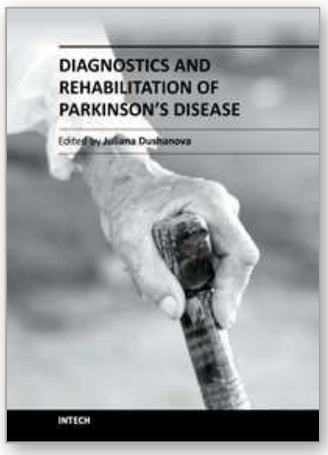
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**Diagnostics and Rehabilitation of Parkinson's Disease**
Edited by Dr. Juliana Dushanova

ISBN 978-953-307-791-8
Hard cover, 528 pages
**Publisher** InTech
**Published online** 07, December, 2011
**Published in print edition** December, 2011

Diagnostics and Rehabilitation of Parkinson's Disease presents the most current information pertaining to news-making topics relating to this disease, including etiology, early biomarkers for the diagnostics, novel methods to evaluate symptoms, research, multidisciplinary rehabilitation, new applications of brain imaging and invasive methods to the study of Parkinson's disease. Researchers have only recently begun to focus on the non-motor symptoms of Parkinson's disease, which are poorly recognized and inadequately treated by clinicians. The non-motor symptoms of Parkinson's disease have a significant impact on patient quality of life and mortality and include cognitive impairments, autonomic, gastrointestinal, and sensory symptoms. In-depth discussion of the use of imaging tools to study disease mechanisms is also provided, with emphasis on the abnormal network organization in parkinsonism. Deep brain stimulation management is a paradigm-shifting therapy for Parkinson's disease, essential tremor, and dystonia. In the recent years, new approaches of early diagnostics, training programmes and treatments have vastly improved the lives of people with Parkinson's disease, substantially reducing symptoms and significantly delaying disability. Written by leading scientists on movement and neurological disorders, this comprehensive book should appeal to a multidisciplinary audience and help people cope with medical, emotional, and practical challenges.

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Jessica Davies, Hoe Lee and Torbjorn Falkmer (2011). An Investigation into the Impact of Parkinson's Disease upon Decision Making Ability and Driving Performance, Diagnostics and Rehabilitation of Parkinson's Disease, Dr. Juliana Dushanova (Ed.), ISBN: 978-953-307-791-8, InTech, Available from: http://www.intechopen.com/books/diagnostics-and-rehabilitation-of-parkinson-s-disease/an-investigation-into-the-impact-of-parkinson-s-disease-upon-decision-making-ability-and-driving-per

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