PAPER

Quantitative assessment of driving performance in Parkinson's disease

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Objectives: The primary aim of this study was to determine how Parkinson's disease (PD) affects driving performance. It also examined whether changes in driver safety were related to specific clinical disease markers or an individual's self rating of driving ability.

Methods: The driving performance of 25 patients with idiopathic PD and 21 age matched controls was assessed on a standardised open road route by an occupational therapist and driving instructor, to provide overall safety ratings and specific driving error scores.

Results: The drivers with PD were rated as significantly less safe ($p<0.05$) than controls, and more than half of the drivers with PD would not have passed a state based driving test. The driver safety ratings were more strongly related to disease duration ($r=-0.60$) than to their on time Unified Parkinson's Disease Rating Scale ($r=-0.24$). Drivers with PD made significantly more errors than the control group during manoeuvres that involved changing lanes and lane keeping, monitoring their blind spot, reversing, car parking, and traffic light controlled intersections. The driving instructor also had to intervene to avoid an incident significantly more often for drivers with PD than for controls. Interestingly, driver safety ratings were unrelated to an individual's rating of their own driving performance, and this was the case for all participants.

Conclusions: As a group, drivers with PD are less safe to drive than age matched controls. Standard clinical markers cannot reliably predict driver safety. Further studies are required to ascertain whether the identified driving difficulties can be ameliorated.

Parkinson's disease (PD) is a progressive neurodegenerative disease that affects motor and sometimes cognitive function, which could potentially impair driving performance, thereby limiting mobility and independence. Few studies have evaluated driving performance in PD. An exception has been the potential impact of medication induced sleep episodes on driving performance.[1] However, these studies have methodological problems,[2] and sleep episodes are arguably a less important source of driving difficulties than those that stem directly from the disease.[3] For example, in addition to the cardinal symptoms of bradykinesia, tremor, and rigidity, several less obvious deficits include difficulties in movement planning,[4] movement sequences,[5] and simultaneous movements,[6] in addition to subtle visual defects and impairments in shifting attentional set.[7] Therefore, it is imperative to characterise fully the impact of PD on driving performance.

Madeley *et al* reported longer reaction times and reduced steering accuracy in a driving simulator in a small sample of patients with PD compared with controls.[8] These impairments were significantly related to the PD group's Webster scores. Lings and Dupont[9] also found increased reaction times and directional errors in PD using a simulator, but did not find a relation between the Webster scale and driving simulator performance. Recently Zesiewicz *et al* also used a simulator to assess PD driving performance; however, the only reported driving measure was the number of collisions, which was higher in those with PD than in control drivers, and was related to both the Hoehn and Yahr scale and the Unified Parkinson's Disease Rating Scale (UPDRS).[10] Despite the known limitations of simulators,[11] all of these studies demonstrated poorer driving skills in the individuals with PD compared with controls.

Although no studies have dealt with state reported crash rates for PD, Dubinsky and colleagues[12] found that crashes (self reported retrospectively over three years) were more common in drivers with PD than in controls, and were related both to the Hoehn and Yahr rating and to dementia (Mini Mental State Examination; MMSE). However, the relation between self reported crash rates and state registered crashes has proved to be inconsistent.[13]

Only two studies, undertaken in Scandinavia[14] and the UK,[15] have assessed the on road driving performance of drivers with PD. Heikkilä *et al* reported that drivers with PD were significantly less safe than controls, with 35% rated as being unsafe to drive, and reported a low level of agreement between safety ratings of the neurologist and the driving instructor, compared with safety self ratings of drivers with PD.[14] A combination of slowed visual processing, levodopa dosage, and age was shown to explain 67% of the variance in driving test scores in drivers with PD.[14] Recently, Radford *et al* assessed drivers with PD on the open road, but included no control group.[15] In contrast to Heikkilä *et al*,[14] they found that only six of 33 drivers with PD were rated as unsafe, but this discordant finding may have resulted from selection bias, because participants were volunteers rather than a consecutive patient series. The use of a control group recruited in the same manner and from the same community groups assumes greater importance in such situations. Like Madeley *et al*,[8] they found a link between the Webster scale and driving performance, although the small number of unsafe drivers in the sample limits this finding's validity.

Our present study investigated the effect of PD on overall driving safety and specific aspects of driving performance on the open road, using well established, quantitative scoring methods. A further aim was to determine whether any

Abbreviations: MMSE, Mini Mental State Examination; PD, Parkinson's disease; UPDRS, Unified Parkinson's Disease Rating Scale

Table 1 Group mean (SD) of the characteristics of the participant groups

	Parkinson's disease	Control participants
Age (years)	63.7 (6.8)	65.2 (8.6)
UPDRS score	27.4 (11.3)	
Hoehn and Yahr	2.3 (0.7)	
Disease duration (years)	6.2 (4.6)	
Mean levodopa dosage (mg)	672.6 (512.5)	

UPDRS, Unified Parkinson's Disease Rating Scale.

changes in driver safety could be predicted by clinical disease markers or an individual's rating of their own driving ability.

METHODS

Participants

Twenty five participants (21 men, four women) with a diagnosis of idiopathic PD and 21 control participants (18 men, three women) in good general health, who drove at least one day each week, performed an on road driving assessment. All participants scored 24 or more on the MMSE,[16] and none was excluded on the basis of dementia. All participants were community dwelling volunteers who had attended presentations at PD support group meetings. The clinical indicators recorded for participants with PD from the participating neurologist included time since the onset of PD symptoms, on time Hoehn and Yahr score, UPDRS (subscales and overall scale), and current levodopa dosage where available. Four of the participants were taking artane, and three of these patients were also taking levodopa medications. There was no significant difference between the safety ratings of those participants with PD who were taking artane and those not on this medication. The mean age of the participants with PD and the controls did not differ significantly ($t_{44} = 0.67$; $p = 0.51$). All testing (driving and laboratory based) was undertaken when the participants were optimally medicated. Table 1 summarises the group characteristics.

Our study was conducted in accordance with the requirements of the Queensland University of Technology human research ethics committee. All participants were given a full explanation of the experimental procedures and written informed consent was obtained, with the option to withdraw from the study at any time.

To obtain an overall sense of the driving characteristics and perceptions of the participants, a previously validated 57 item questionnaire was administered.[17] Questions related to driving experience and habits, perceived difficulty (on a scale of 1 (quite difficult) to 5 (quite easy)) for 24 specific situations, and perceived difficulty (on the same 5 point scale) for 12 specific tasks. The questionnaire also included items relevant to PD, such as problems with moving the foot from one pedal to another.

Driving performance

Driving performance was measured in an automatic, dual brake vehicle under in traffic conditions using a previously validated technique.[18 19] An accredited professional driving instructor, experienced in assessment, sat in the front passenger seat and was responsible for maintaining vehicle safety. A driver trained occupational therapist, experienced in the assessment of driving and rehabilitation, sat in the rear seat. Both assessed driving safety independently, using well defined criteria. Neither was aware of the categorisation of the participants.

All participants were directed to drive along the same 19.4 km open road route that contained a range of typical driving situations. Seventy per cent of the driving was under directed instruction and 30% was under self directed navigation, where the participant had to find their own way to a particular destination.

Occupational therapist assessment

The occupational therapist scored seven aspects of driving performance at 147 locations along the route (general observation, observation of blind spots, indication (signalling), braking/acceleration, lane positioning, gap selection, and approach). Failing any aspect of performance resulted in failure of the whole task for a given location, giving an overall score representing the percentage of locations where no errors were made. The number of each error type was also recorded. In addition, each of the 147 locations was allocated to one of nine categories, including roundabouts, merging, pulling in/pulling out, traffic light and non-traffic light controlled intersections, reversing and parking, one way and two way traffic, and lane changing. This allowed the identification of situations where drivers had the most difficulty.

The occupational therapist also gave an overall safety rating from 1 to 10, according to current transport licensing standards. A score between 1 and 3 indicated that the instructor had to take action to avoid an incident, or that the driver hit a significant object and should consider ceasing

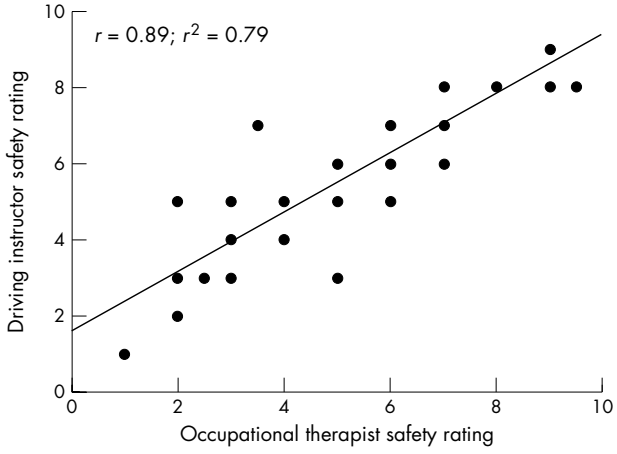

Figure 1 Correlation between the global driver safety ratings for all participants assigned by the occupational therapist and the driving instructor. The figure includes many overlying points.

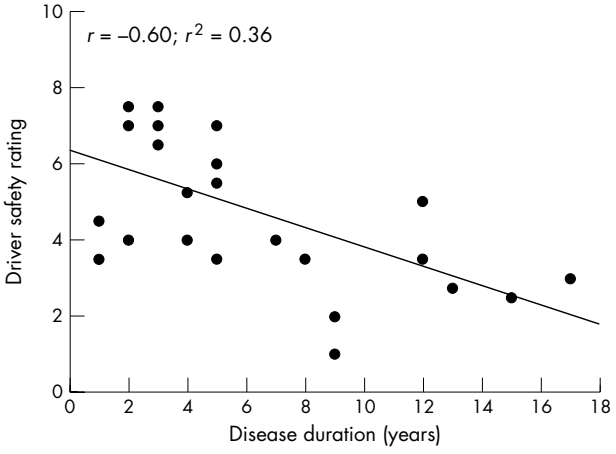

Figure 2 The association between the time since diagnosis of Parkinson's disease (PD) and average driver safety rating for each of the participants with PD. The figure includes some overlying points.

Table 2 Overall driving score and types of driving errors made by the two groups as assessed by the occupational therapist

	Participant groups		Statistics	
Driving scores	**Controls**	**Parkinson's**	**t Value**	**p Value**
Overall score %	83.95 (1.61)	77.18 (2.15)	2.43	0.02
Critical errors	0.38 (0.17)	1.12 (0.36)	−1.75	0.09
Observation errors	3.14 (0.63)	5.04 (0.93)	−1.62	0.11
Blind spot errors	5.19 (0.66)	7.52 (0.74)	−2.30	0.03
Indicator errors	6.09 (0.58)	6.80 (0.77)	−0.71	0.48
Brake/accelerator errors	8.19 (1.26)	9.80 (1.76)	−0.72	0.48
Lane keeping errors	4.62 (1.00)	10.20 (1.62)	−2.80	0.01
Gap selection errors	3.62 (0.60)	4.40 (0.63)	−0.89	0.38
Approach errors	8.28 (1.24)	10.36 (1.57)	−1.00	0.32
Directed errors	27.14 (3.64)	38.60 (4.40)	−1.96	0.06
Self directed errors	12.00 (1.89)	15.52 (2.26)	−1.17	0.25

Values are mean (SD).

driving. A score of 4 or 5 indicated poor driving and observation skills, whereas a score in the range of 6 to 8 indicated average driving skills, but with some bad habits. Finally, a score of 9 or 10 reflected good to excellent driving and observational skills.

Driving instructor assessment

The driving instructor provided an independent overall safety rating using the same scoring criteria as the occupational therapist. In addition, he recorded the number of critical and non-critical driving errors made, and the number of instructor interventions.

Participants rated the difficulty of the driving route and conditions compared with their typical driving (on a scale of 1–5, where "1 = much easier" to "5 = much harder"), and their performance on the test compared with the typical driver (on a scale of 1–5, where "1 = excellent" to "5 = poor").

Data analysis

The driving data were analysed using independent group *t* tests to identify any group differences with directed or self directed navigational instruction, and were broken down into error types and locations. The familywise error rate was not corrected for because, as this is one of the first descriptions of driving error types and locations in PD, it was thought important not to miss potential problem areas by using unduly conservative methods. The safety ratings of the occupational therapist and driving instructor were compared to determine the level of inter-rater agreement, in addition to the association with disease markers (time since diagnosis, on time UPDRS and Hoehn and Yahr scale). For the driving history questionnaire, those questions for which participants used a scale from 1 to 5 were analysed parametrically using independent *t* tests, whereas others were analysed non-parametrically (Mann-Whitney U test). Modal categories are reported as the measure of central tendency.

RESULTS

Driving history questionnaire

Drivers with PD and controls had similar driving experience (modal category for both groups, "41–50 years"; U = 238; p = 0.56). Similarly, there were no significant group differences for frequency of driving (modal category for both groups, "every day"; U = 238; p = 0.55), amount of time driven each week (modal category for participants with PD, "3–4 hours/week" and for the controls, "> 7 hours/week"; U = 203.5; p = 0.18*), confidence felt when driving (modal category for both groups, "confident"; U = 236; p = 0.51), amount of long distance (modal category for both groups, "1–2 times/year"; U = 241.5; p = 0.19) or highway driving (modal category for both groups, "a few times each month"; U = 215; p = 0.37), or driving in unfamiliar areas (modal category for both groups, "confident"; U = 231; p = 0.10). There were also no significant differences between groups for self reported crashes (modal category for both groups, "no crash within past 10 years"; U = 259; p = 0.92), with seven of the 21 controls and eight of the 25 participants with PD reporting a crash within the previous 10 years.

However, the drivers with PD reported driving significantly fewer kilometres than controls (modal category, "60–90" compared with "> 90 km/week"; U = 144.5; p = 0.004), and were significantly less confident driving alone (modal category, "confident" compared with "very confident"; U = 167.5; p = 0.015). Only three of the 36 driving conditions or tasks were rated as significantly more difficult by the drivers with PD (on a scale of 1 to 5): reading road

*This apparent difference was caused by a non-normal distribution: a subgroup of the controls drove longer distances. However, the mean values were in the same category of 3–4 hours/week.

Table 3 Locations at which driving errors were made by the two groups as assessed by the occupational therapist

	Participant groups		Statistics	
Locations	**Controls**	**Parkinson's**	**t Value**	**p Value**
Roundabouts	4.71 (0.68)	4.56 (0.75)	0.15	0.88
Merging	1.33 (0.26)	2.16 (0.37)	−1.75	0.09
Pulling in/pulling out	4.19 (0.36)	3.92 (0.29)	0.59	0.56
Traffic light controlled intersection	6.23 (1.00)	10.36 (1.73)	−1.95	0.05
Non-traffic light controlled intersections, stop and give way	4.19 (0.86)	6.64 (1.17)	−1.64	0.11
Reversing, car parking	2.28 (0.57)	3.84 (0.54)	−1.98	0.05
One way (no oncoming traffic)	3.33 (0.67)	4.92 (0.70)	−1.62	0.11
Two way (oncoming traffic)	6.09 (1.38)	7.72 (1.11)	−0.92	0.36
Lane changing	5.85 (1.02)	8.84 (1.11)	−1.94	0.05

Values are mean (SD).

signs in daylight (t_{44} = 2.41; p = 0.02), moving their foot from one pedal to another (t_{44} = 2.73; p = 0.009), and steering (t_{44} = 2.80; p = 0.008). However, in all cases, groups differed by no more than one category—for example, ''fairly easy'' versus ''quite easy''.

Driver safety ratings: occupational therapist and driving instructor assessments

The safety ratings recorded for each of the participants with PD and the controls by the occupational therapist and driving instructor were highly correlated (fig 1), so we used the mean of the two raters' scores. These show that the drivers with PD were rated as significantly less safe on a scale of 1–10 (mean, 4.80; SD, 1.91) than the controls (mean, 6.56; SD, 1.72) (t_{44} = 3.26; p = 0.002).

When the safety ratings were considered individually, five of the 25 drivers with PD scored between 1 and 3, a score defined as a driver for whom the instructor had to take action to avoid an incident, or the driver hit a significant object and should consider ceasing driving. Furthermore, 14 of the 25 drivers with PD scored 5 or less, indicating that they would have failed the Queensland driving test, as compared with five of the 21 controls.

Examination of the safety ratings of the drivers with PD and clinical disease indicators showed that time since diagnosis was significantly correlated with driver safety ratings (r = −0.60; p = 0.001)—the longer the time since diagnosis, the lower the patient's rating (fig 2). This association remained significant even when age was partialled out ($r_{1,2.3}$ = −0.47; p = 0.02). However, driver safety ratings were not significantly correlated with either on time UPDRS (r = −0.24; p = 0.25), the Hoehn and Yahr scale (r = −0.06; p = 0.79), or levodopa dosage (r = −0.36; p = 0.11).

Self reported driving and safety rating

Those in the PD group rated their driving skills more poorly compared with an average driver (M = 2.98) than did the controls (M = 2.57), and these differences reached significance (t_{44} = −2.71; p = 0.009). However, those with PD did not rate the driving route and conditions as harder than the control participants (patients with PD, M = 3.4; controls, M = 3.19; t_{44} = −1.20; p = 0.24). Importantly, there was no relation between an individual's self rating of driving performance and their safety rating (r = −0.22; p = 0.14), and this was the case for both the drivers with PD and the controls.

Types and locations of driving errors

The overall safety scores recorded by the occupational therapist were significantly worse for the PD group than for controls, and both groups made proportionally more errors under self directed than directed navigation, but these differences did not reach significance (table 2). The drivers with PD made significantly more errors involving lane keeping and observation or monitoring of the blind spot than did the controls.

Table 3 shows the breakdown of errors by location type. The drivers with PD made significantly more errors at traffic light controlled intersections and at locations involving reversing, car parking, and lane changing.

Driving instructor

Apart from rating the drivers with PD as less safe than controls, the driving instructor also had to intervene more often to avoid an incident than for the controls (table 4). The drivers with PD also made significantly more critical errors than did the controls.

DISCUSSION

The drivers with PD were rated as significantly less safe than control participants by both the occupational therapist and the driving instructor on a standardised open road course. This finding is in general agreement with that of Heikkilä *et al*,[14] who reported that 35% of drivers with PD were rated as unsafe to drive compared with control subjects. Radford *et al* reported similar findings but did not include a control group.[15]

The drivers with PD made significantly more errors than controls in lane keeping and lane changing, reversing, parking, monitoring of their blind spot, and negotiating traffic light controlled intersections. The driving instructor also had to intervene significantly more often for drivers with PD. These errors probably stem from some combination of decreased motor control skills, impaired visuo-spatial processing, sequence control, and planning in the drivers with PD. However, the current data do not allow this impaired performance to be attributed to any specific process. These practical skill findings agree with the questionnaire data from the drivers with PD, which showed that these patients had significantly more problems with steering and moving their feet between pedals. They also confirm the findings of Radford *et al*,[15] that patients with PD display a lack of observation at junctions, poor road positioning, and poor driving at roundabouts. However, their results must be considered with caution because of their limited sample size.

Importantly, the global driver safety ratings could not be predicted by the on time UPDRS or the Hoehn and Yahr scale, but had a stronger association with disease duration. Although previous studies have reported that various indices of driving performance have been predicted by the Webster's,[8] Hoehn and Yahr,[12] and UPDRS scales,[10] there has been considerable disagreement in the literature.[9] Some researchers have used driving simulators, which have been shown to be poor predictors of true performance,[11] or report on small and potentially unrepresentative samples. Indeed, Heikkilä *et al* found that speed of visual processing, medication use, and age were better predictors of open road driving performance than were clinical disease indicators, although, as in our study, the association between levodopa dosage and driving safety alone was not strong.[14] These findings confirm the fact that currently used clinical disease markers do not adequately capture those aspects of PD that are linked with unsafe driving performance.

Table 4 Driving performance scores recorded by the driving instructor

	Participant groups		Statistics	
Driving scores	Controls	Parkinson's	t Value	p Value
Instructor interventions	0.14 (0.08)	0.64 (0.18)	−2.36	0.02
Critical errors	0.76 (0.30)	2.24 (0.58)	−2.14	0.04
Non-critical errors	3.09 (0.32)	3.44 (0.37)	−0.69	0.49

Values are mean (SD).

The questionnaire findings suggest that the drivers with PD in this volunteer sample limit their own driving habits only to a minor degree, driving as often as controls, but covering fewer kilometres and driving alone less often. These findings are not surprising given that the individuals with PD and controls reported similar driving confidence levels. Importantly, an individual's self rated performance was a poor predictor of their driving safety, and this was true for all participants. This finding confirms the conclusion of Heikkilä *et al*,[14] and suggests that it is unrealistic to expect individuals, with or without PD, to determine their own safety levels. Instead, it emphasises the importance of identifying objective, evidence based predictors of driving safety, which can be used to inform the treating practitioner and the licensing authority, and to educate and assist drivers in the use of compensatory behaviours. This was the objective of a larger study conducted by our research group, which includes the evaluation of visual, cognitive, and motor tests as predictors of safe driving performance.

It is also important to note that the drivers with PD in our study had chosen to continue driving, had retained their licence, and had volunteered to participate in our study—and are therefore likely to drive better than average, given that many patients with PD choose to stop driving.[20] The current results probably overestimate the driving performance of the wider PD population, and may under-represent the true driving performance decrement that accompanies the disease. In addition, these driving performance scores were obtained during optimal on time medication and do not address the impact of symptom fluctuations in PD.

CLINICAL IMPLICATIONS

Together, these findings have important implications that should be considered by health professionals dealing with patients with PD.

- At diagnosis, drivers with PD need advice regarding the potential impact of PD on driving, given that our study provides clear evidence that drivers with PD are significantly less safe than control drivers.
- Drivers with PD probably have limited awareness of their deteriorating driving performance and need regular monitoring. It is unrealistic to expect individuals, particularly those with PD, to be aware that their driving is becoming unsafe and to adopt compensatory behaviours. This clearly indicates the importance of identifying predictors of unsafe performance and making them available for use by a patient's neurologist and to assist in the licensing process.
- Appropriately timed referral to occupational therapy driving assessment services to determine fitness to continue driving or the need for driving rehabilitation may enable drivers with PD to make more realistic plans for the future, whether to limit their driving, or stop altogether.
- Drivers with PD may benefit from targeted driver retraining. Our study clearly indicates that there are specific areas of difficulty that are more common in individuals with PD. It may be possible to use targeted interventions and retraining to prolong the length of time that patients with PD might drive safely and hence maintain their independence.

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