# Road safety in drivers with Parkinson disease

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## ABSTRACT

**Objective:** To assess road safety and its predictors in drivers with Parkinson disease (PD).

**Methods:** Licensed, active drivers with PD (n = 84; age = 67.3 ± 7.8, median Hoehn & Yahr stage II) and controls (n = 182; age = 67.6 ± 7.5) underwent cognitive, visual, and motor tests, and drove a standardized route in urban and rural settings in an instrumented vehicle. Safety errors were judged and documented by a driving expert based on video data review.

**Results:** Drivers with PD committed more total safety errors compared to controls (41.6 ± 14.6 vs 32.9 ± 12.3, $p < 0.0001$); 77.4% of drivers with PD committed more errors than the median total error count of the controls (medians: PD = 39.5, controls = 31.0). Lane violations were the most common error category in both groups. Group differences in some error categories became insignificant after results were adjusted for demographics and familiarity with the local driving environment. The PD group performed worse on tests of motor, cognitive, and visual abilities. Within the PD group, older age and worse performances on tests of visual acuity, contrast sensitivity, attention, visuospatial abilities, visual memory, and general cognition predicted error counts. Measures of visual processing speed and attention and far visual acuity were jointly predictive of error counts in a multivariate model.

**Conclusions:** Overall, drivers with Parkinson disease (PD) had poorer road safety compared to controls, but there was considerable variability among the drivers with PD, and some performed normally. Familiarity with the driving environment was a mitigating factor against unsafe driving in PD. Impairments in visual perception and cognition were associated with road safety errors in drivers with PD. ***Neurology*® 2009;73:2112–2119**

## GLOSSARY

**ADL** = activities of daily living; **AVLT** = Auditory Verbal Learning Test; **BVRT** = Benton Visual Retention Test; **CFT** = Complex Figure Test; **COWA** = Controlled Oral Word Association; **CS** = contrast sensitivity; **ESS** = Epworth Sleepiness Scale; **FVA** = far visual acuity; **GDS** = Geriatric Depression Scale; **JLO** = Judgment of Line Orientation; **MMSE** = Mini-Mental State Examination; **NVA** = near visual acuity; **NS** = nonsignificant; **PD** = Parkinson disease; **SE-ADL** = Schwab-England Activities of Daily Living; **SFM** = Structure from Motion; **UFOV** = useful field of view; **UPDRS** = Unified Parkinson's Disease Rating Scale.

Parkinson disease (PD) is a relatively common, disabling, progressive neurodegenerative disorder of aging with motor, cognitive, and visual dysfunction (~0.3% in the general population and 3% in those over the age of 65).[1,2] The number of senior drivers is projected to increase fivefold from 1986 to 2028 in North America,[3] potentially increasing the number of drivers with PD and posing challenges for healthcare providers in determining their fitness to drive.

There are no well-established epidemiologic data on crash risk in PD.[4] However, PD appears to be associated with decreased driving performance[5-12] and increased crashes, especially in those with poorer motor and cognitive dysfunction[13] and excessive daytime sleepiness.[14] Patients themselves or their neurologists may not be capable of reliably evaluating driving ability.[6]

**Supplemental data at www.neurology.org**

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A standardized road test can be used as an index of driver safety.[15] We hypothesized that drivers with PD commit more safety errors (primary outcome measure = total error count) compared to neurologically normal drivers on a standardized road test, and determined the cognitive, visual, and motor predictors of road safety errors within the PD group. As most traffic maneuvers demand a combination of visual, cognitive, and motor abilities, we expected that the PD group would be worse in most error categories. We expected tests of visual perception, visuospatial abilities, attention, and executive functions would be more predictive than memory and motor tests. Our findings may assist healthcare providers, families, and patients in predicting road safety and advising PD drivers at risk.

## METHODS

Details of methods can be found in appendix e-1: Methods on the *Neurology*® Web site at www.neurology.org.

**Subjects.** All subjects were community dwelling, independently living, licensed active drivers.

Drivers with PD were recruited from the Movement Disorders Clinics at the Department of Neurology, University of Iowa, and Veterans Affairs Medical Center, both in Iowa City.

**Inclusion criteria.** Active drivers with idiopathic PD and elderly drivers without neurologic disease (control group) were enrolled. All had a valid state driver's license and driving experience of greater than 10 years.

**Exclusion criteria.** Exclusion criteria were cessation of driving prior to encounter; acute illness or active, confounding medical or psychiatric conditions; other neurologic disease leading to dementia and motor dysfunction (excluded by review of medical records, available imaging studies, cognitive testing, clinical interview, and physical examination); secondary parkinsonism; Parkinson-plus syndromes; recent treatment with centrally acting dopaminergic blockers or investigational drugs; diseases of the optic nerve, retina, or ocular media with corrected visual acuity less than 20/50.

**Standard protocol approvals, registrations, and patient consents.** The study was approved by the Institutional Review Boards and Human Subjects Office of the University of Iowa. A written informed consent was obtained from all participants in the study.

**Off-road testing battery.** The battery methodology is explained in detail in our recent work.[2] For all tests, raw scores were used for analysis.

**The road test.** The experimental drive was conducted aboard ARGOS, a mid-sized instrumented vehicle with an automatic transmission and hidden instrumentation and sensors.[5,11,12,16-18] The road test was usually administered within a few weeks of cognitive and visual testing, sometimes on the same day. The experimental drive lasted approximately 45 minutes, and the subjects drove across residential city streets, suburban commercial strips, rural 2-lane highways, and a 4-lane 65 mph speed limit freeway. Drivers were tested in the "on" state, and under good visibility and road conditions.

Driver familiarity with the testing route was assessed (as "yes" or "no" obtained by asking the driver about prior driving experience in and around Iowa City)[12] and incorporated as a factor into analyses.

**Safety errors.** A professional driving instructor, different from the person who administered the drive, reviewed the video data.[18,19] As shown in our previous work,[11] the driving instructor reviewed tapes with a multiplex view using 4 channels of video (including forward roadway the driver should see and position of the car relative to the lane) with superimposed digital driving data, which included speed, enabling comparison of the actual speed to the speed limit at any moment of the drive and detection of lane deviation errors. This approach allowed a standard review of all drives, including multiple views of the driver, car, road, and traffic. The reviewer assessed the number and type of safety errors committed by the subjects, using a list of 76 error types (e.g., "unsafe passing") organized into 15 categories (e.g., "stop signs," "lane observance").[18,19] This list was based on the Iowa Department of Transportation's Drive Test Scoring Standards (September 7, 2005, version). The subjects were told to drive as they would in their usual life and there was no overall pass/fail judgment.[18] The primary outcome measure was the total number of safety errors. All other comparisons (error categories, "serious" errors) were of exploratory nature. Of the 76 error types, 30 were classified as "serious," which were seen across different error categories.[18,19] The "serious" errors were those that were classified as "failure" errors by the Iowa Department of Transportation. However, as the subjects did not take this road test as an official licensing test and we did not use a pass/fail system, we classified these errors as "serious" errors. For each subject, we tabulated the total number of safety errors, the number of safety errors within each category, and the total number of "serious" safety errors.

Using randomly chosen 30 drive video tapes (10 with PD, 10 with Alzheimer disease, and 10 controls) across the studies in our laboratory for repeated analysis, the intrarater correlation for total safety error counts was 95%, while the interrater correlation (review by a second professional driving instructor with similar qualifications and experience) was 73%, as we previously reported.[18]

**Statistical analysis.** We used the Wilcoxon rank sum test to compare the PD and control groups with respect to demo-

**Table 1** Characteristics of subjects with Parkinson disease (PD)

| PD characteristic (n = 84) | Value |
|---|---|
| Age, y | 67.3 (7.8) |
| Disease duration, y | 5.9 (5.0) |
| Hoehn & Yahr stage (↓) | 2.2 (0.59) |
| UPDRS-ADL (↓) | 7.7 (3.6) |
| UPDRS-motor (↓) | 24.1 (8.9) |
| Schwab-England score (↑) | 84.3 (9.6) |
| Levodopa equivalent, mg/day | 588 (588) |

Values expressed as mean (SD).
UPDRS = Unified Parkinson's Disease Rating Scale; ADL = activities of daily living; ↑ = higher score better; ↓ = lower score better.

**Table 2** Characteristics of Parkinson disease (PD) and normal control groups

| Category/function/measure | PD (n = 84) | Controls (n = 182) | p Value |
|---|---|---|---|
| **Demographics** | | | |
| Age, y | 67.3 (7.8) | 67.6 (7.5) | 0.9453 |
| Education, y | 14.7 (2.7) | 15.7 (2.5) | 0.0015 |
| Gender (male) | 69 (82.1%) | 92 (50.6%) | <0.0001 |
| **Driving characteristics** | | | |
| Familiarity | 18 Familiar | 99 Familiar | <0.0001 |
| Days driven | 5.8 (1.7) | 6.1 (1.3) | 0.6268 |
| Miles per week | 165.4 (171.3) | 142.8 (163.0) | 0.4312 |
| **Basic visual sensory functions** | | | |
| NVA (logMAR) (↓) | 0.08 (0.09) | 0.02 (0.04) | <0.0001 |
| FVA (logMAR) (↓) | 0.00 (0.11) | −0.07 (0.12) | <0.0001 |
| CS (Pelli Robson chart) (↑) | 1.68 (0.16) | 1.80 (0.16) | <0.0001 |
| **Visual perception** | | | |
| Motion perception: SFM (%) (↓) | 12.5 (5.1) | 10.2 (2.8) | 0.0005 |
| Attention: UFOV (ms) (↓) | 875 (349) | 630 (221) | <0.0001 |
| Spatial perception: JLO (↑) | 23.9 (4.4) | 26.2 (3.5) | <0.0001 |
| **Visual cognition** | | | |
| Construction: Blocks (↑) | 32.3 (10.9) | 39.9 (10.1) | <0.0001 |
| Construction: CFT-Copy (↑) | 26.5 (4.9) | 31.0 (3.7) | <0.0001 |
| Memory: CFT-Recall (↑) | 13.0 (5.1) | 15.7 (5.7) | 0.0012 |
| Memory: BVRT-Error (↓) | 7.4 (3.9) | 4.4 (2.4) | <0.0001 |
| **Executive functions** | | | |
| Set shifting: TMT (B-A) (s) (↓) | 87.1 (79.9) | 46.1 (32.6) | <0.0001 |
| Verbal fluency: COWA (↑) | 34.8 (10.6) | 38.7 (11.1) | 0.0074 |
| **Verbal memory** | | | |
| AVLT-Recall (↑) | 7.40 (3.7) | 10.08 (3.2) | <0.0001 |
| **General cognition** | | | |
| MMSE (↑) | 28.2 (1.8) | 29.3 (0.9) | <0.0001 |
| COGSTAT (↑) | 342 (77) | 407 (44) | <0.0001 |
| **Depression** | | | |
| GDS (↓) | 5.9 (5.6) | 2.9 (3.3) | <0.0001 |
| **Sleepiness** | | | |
| ESS (↓) | 10.1 (4.1) | 6.7 (3.3) | <0.0001 |
| **Motor function** | | | |
| Speed: Finger tapping/20 s (↑) | 35.5 (5.9) | 49.3 (9.7) | <0.0001 |
| Speed: 7 m walk (s) (↓) | 14.0 (4.0) | 9.3 (1.7) | <0.0001 |
| Balance: FR (in.) (↑) | 11.2 (3.3) | 12.9 (2.7) | <0.0001 |

Values expressed as mean (SD). Groups were compared using Wilcoxon rank sum test. The SD of logMAR scores (0.11) corresponds to a change from 20/20 to 20/25, or 20/25 to 20/32, or 20/32 to 20/40. ↑ = higher score better; ↓ = lower score better.
NVA = near visual acuity; FVA = far visual acuity; CS = contrast sensitivity; SFM = Structure from Motion; UFOV = useful field of view; JLO = Judgment of Line Orientation; CFT = Complex Figure Test; BVRT = Benton Visual Retention Test; TMT = Trail Making Test; COWA = Controlled Oral Word Association; AVLT = Auditory Verbal Learning Test; MMSE = Mini-Mental State Examination; GDS = Geriatric Depression Scale; ESS = Epworth Sleepiness Scale.

graphic, visual, cognitive, motor, and driving safety outcomes. Multiple linear regression was used to adjust for age, education, gender, and familiarity with the driving environment.

We tested for age- and education-adjusted associations between the off-road measures and total safety errors within the PD group using multiple linear regression and expressed regression coefficients in terms of average difference in safety errors per 1 standard deviation difference in each measure. We also modeled the simultaneous effects of our predictors using multiple linear regression.

**RESULTS** The drivers with PD had mild to moderate disease severity (table 1). The group of drivers with PD was less educated and had a larger proportion of males (table 2). The PD group performed worse on neuropsychological and visual tests with deficits in the mild to moderate range (table 2), suggesting that a proportion of drivers with PD might have mild cognitive impairment, which can be observed even in the early, untreated phase of the disease.[20]

Drivers with PD committed more at-fault safety errors, both in total counts (41.6 ± 14.6 vs 32.9 ± 12.3, $p < 0.0001$) and serious error counts (2.4 ± 2.3 vs 1.7 ± 1.6, $p = 0.0185$) than the neurologically normal controls (table 3). Only 10 categories are listed in table 3 as other error categories were not observed. The significance for group difference persisted after adjusting for age, education, gender, and familiarity with the environment for the total error counts ($p = 0.0057$). For the more serious errors, significance for group differences was maintained after adjustment for age, education, and gender ($p = 0.0004$), but not after familiarity was added to the model ($p = 0.1001$). Drivers with PD committed more errors than controls in the categories of lane observance (16.5 ± 10.4 vs 11.6 ± 7.9) and stop signs (4.9 ± 2.2 vs 4.2 ± 2.1); these significant differences persisted after adjusting for age, education, gender, and familiarity. Likewise, the drivers with PD made significantly more errors in the categories of turns (6.2 ± 2.9 vs 5.0 ± 2.6), speed control (4.5 ± 3.0 vs 3.2 ± 2.9), starting and pulling away from shoulder (0.9 ± 0.8 vs 0.7 ± 0.8), and parallel parking (0.4 ± 0.5 vs 0.2 ± 0.5), but these differences became nonsignificant after adjustments, especially for familiarity, as shown in table 3. The controls made more errors during overtaking (0.0 ± 0.0 in PD vs 0.1 ± 0.4), but this was not significant after adjusting for familiarity. There were no significant group differences on curves, during lane change, at railroad crossings, and traffic signals.

In exploratory analyses on safety classification, 77.4% of drivers with PD committed more errors than the median total error count of the controls (31 errors). The total error counts of 54.8% of drivers with PD were higher than the worst quartile (cutoff = 38) of controls, while 21.4% of drivers with PD performed worse than the worst decile (cutoff = 51) of controls. Hence, drivers with PD generally

Table 3 Driver safety errors in Parkinson disease (PD) (n = 84) and normal control (n = 182) groups

| Safety error category | PD | Controls | p Value crude | Age, education, gender adjusted | Age, education, gender, familiarity adjusted |
|---|---|---|---|---|---|
| Total | 41.6 (14.6) | 32.9 (12.3) | <0.0001 | <0.0001 | 0.0057 |
| Lane observance | 16.5 (10.4) | 11.6 (7.9) | <0.0001 | 0.0002 | 0.0077 |
| Turns | 6.2 (2.9) | 4.9 (2.6) | 0.0007 | 0.0007 | 0.2963 |
| Lane change | 5.0 (2.6) | 4.8 (2.7) | 0.3323 | 0.6776 | 0.6676 |
| Stop signs | 4.9 (2.2) | 4.2 (2.1) | 0.0212 | 0.0222 | 0.0251 |
| Control of speed | 4.5 (3.0) | 3.2 (2.9) | 0.0005 | 0.0005 | 0.2783 |
| Traffic signals | 2.3 (1.3) | 2.2 (1.6) | 0.3756 | 0.9610 | 0.9411 |
| Pulling away from curb | 0.9 (0.8) | 0.7 (0.8) | 0.0382 | 0.1428 | 0.7852 |
| Parallel parking | 0.4 (0.5) | 0.2 (0.4) | 0.0006 | 0.0077 | 0.9310 |
| Curves | 0.00 (0.00) | 0.01 (0.07) | 0.5020 | 0.5615 | 0.8935 |
| Railroad crossing | 0.04 (0.2) | 0.1 (0.5) | 0.2923 | 0.2415 | 0.5872 |
| Overtaking | 0.0 (0.0) | 0.1 (0.4) | 0.0069 | 0.0512 | 0.1611 |
| Serious errors | 2.4 (2.3) | 1.7 (1.6) | 0.0185 | 0.0004 | 0.1001 |

Values expressed as mean (SD). Crude *p* value by Wilcoxon rank sum test, adjustments using regression techniques.

committed more errors at several quantile levels, although some drivers with PD (22.6%) were at least as safe as the median of the control drivers.

Within the PD group, age was a significant predictor of total safety error counts. In addition, after adjusting for age and education, individual measures of basic visual sensory functions (far visual acuity [FVA], contrast sensitivity [CS]), visual processing speed and attention (useful field of view [UFOV]), motion perception (Structure from Motion [SFM]), visuoconstructional abilities (Complex Figure Test [CFT]-Copy), visual memory (CFT-Recall), and general cognition (Mini-Mental State Examination [MMSE] and COGSTAT) were significant predictors of total error counts (table 4). Table 4 shows the change in error counts for 1 SD change of each predictor. For example, 1 SD decrease in general cognitive function, either measured using MMSE or COGSTAT, resulted in 4.1 points increase in error counts within PD.

A multivariate analysis to predict total road safety errors in subjects with PD revealed UFOV total score ($p = 0.0095$) and FVA ($p = 0.0041$) as simultaneous predictors which gave an appropriate balance of model fit (adjusted $R^2 = 0.2462$, near the maximum achieved) and simplicity (e.g., only 2 predictor variables) when modeled together. According to this model, an increase of 100 msec in total UFOV score corresponded to an increase of 1.1 driving errors, and an increase of 0.1 on FVA corresponded to an average increase of 4.2 driving errors. Table 5 illustrates how these 2 risk factors predict safety errors. For each of these risk factors, we chose low, medium, and high levels (i.e., approximately equal to the mean ± 1 SD) representative of the subjects with PD in our study. Across these ranges of risk factors, table 5 shows that subjects with PD with high-risk profiles tend to commit noticeably more safety errors than those with low-risk profiles. This model assumed that the factor effects were additive, which was supported by the nonsignificant test of interaction ($p > 0.20$ for interaction between UFOV and FVA $p > 0.20$).

Eighty of the 84 drivers with PD reported that they wore corrective lenses to drive. Twelve had corrective lenses/glasses restriction by the Iowa DOT. Video review confirmed that 72 of 80 (11 of 12 with corrective lenses/glasses restriction) were wearing glasses during the ARGOS drive. Resolution of the video was not sufficient to determine potential use of contact lenses in the remainder.

We also looked at an alternative model using CFT-Copy (another strong univariate predictor, table 4; paper-pencil test, quick to administer, and in public domain) and the FVA resulting in an adjusted $R^2$ of 0.214.

**DISCUSSION** The findings in this study support the hypothesis that drivers with PD commit more driving safety errors on the road. The most frequently observed error categories in the PD group were lane observance, turn, lane change, stop sign, speed control, and turn errors. Familiarity with the driving environment was a mitigating factor in drivers with PD. An off-road battery of cognitive, visual, and motor tests predicted safety error counts within the PD group, giving additional information above and beyond PD diagnosis alone.

Our general results are compatible with other studies indicating diminished driving safety in persons with PD.[6-10] Beyond this, the use of an instru-

**Table 4** Changes in total safety errors for a 1 SD increase in cognitive, visual, and motor predictors using multiple linear regression and adjusting for age and education for visual and cognitive predictors within the Parkinson disease (PD) group (n = 84)

| Category/function/measure | Coefficient (SE) |
|---|---|
| **Demographics** | |
| Age | 3.31 (1.57)* |
| Education | −0.23 (1.63) |
| Gender (male) | 2.18 (1.60) |
| **Driving characteristics** | |
| Familiarity | −2.58 (1.85) |
| Days driven | −1.49 (1.64) |
| Miles per week | −2.34 (1.63) |
| **Basic visual sensory function** | |
| NVA | 0.95 (1.68) |
| FVA | 5.78 (1.63)† |
| CS | −3.77 (1.66)* |
| **Visual perception** | |
| Motion perception: SFM % | 3.81 (1.69)* |
| Attention: UFOV | 5.40 (1.74)‡ |
| Spatial perception: JLO | −3.06 (1.59) |
| **Visual cognition** | |
| Construction: Blocks | 0.25 (1.62) |
| Construction: CFT-Copy | −4.58 (1.62)‡ |
| Memory: CFT-Recall | −3.94 (1.61)* |
| Memory: BVRT-Error | 2.86 (1.71) |
| **Executive functions** | |
| Set shifting: TMT (B-A) | 3.12 (1.65) |
| Verbal fluency: COWA | −0.10 (0.17) |
| **Verbal memory** | |
| AVLT-Recall | −0.44 (1.81) |
| **General cognition** | |
| MMSE | −4.14 (1.63)* |
| COGSTAT | −4.06 (1.71)* |
| **Depression** | |
| GDS | 2.49 (1.61) |
| **Sleepiness** | |
| ESS | −0.44 (1.65) |
| **Motor function** | |
| Speed: Finger tapping | −0.48 (1.63) |
| Speed: 7 m walk | 0.29 (1.67) |
| Balance: FR | 0.99 (1.73) |
| **Indices of PD severity** | |
| Disease duration, y | 2.92 (1.65) |
| Hoehn & Yahr stage | 3.20 (1.65) |
| UPDRS-ADL | 2.42 (1.60) |
| UPDRS-Motor | 1.05 (1.72) |
| Schwab-England score | −3.05 (1.61) |
| Levodopa equivalent, mg/d | 1.34 (1.67) |

Motor function and indices of PD severities were adjusted for age only.
*$p < 0.05$, ‡$p < 0.01$, †$p < 0.001$.
NVA = near visual acuity; FVA = far visual acuity; CS = contrast sensitivity; SFM = Structure from Motion; UFOV = useful field of view; JLO = Judgment of Line Orientation; CFT = Complex Figure Test; BVRT = Benton Visual Retention Test; TMT = Trail Making Test; COWA = Controlled Oral Word Association; AVLT = Auditory Verbal Learning Test; MMSE = Mini-Mental State Examination; GDS = Geriatric Depression Scale; ESS = Epworth Sleepiness Scale.

mented vehicle in the current study permitted detailed quantitative assessment of specific aspects of driver performance in the field under actual road conditions. In addition, the relatively large sample size in the current study (84 subjects with PD compared to 20–40 in prior studies[6-10]) provides a more representative picture of the general patterns (e.g., error categories), variability, and predictors of driving performances within PD.

Analysis of at-fault driving safety errors on a standardized driving test provides an objective index of driving safety. Lane position control errors, the most common error in our study, are significantly associated with unsafe driver ratings and road test failure.[21,22] Driving errors on road tests predict independent global pass/fail judgments by experts[21,22] and driver crash history.[15]

Although PD has been recognized primarily as a motor disorder due to degeneration of the dopaminergic nigrostriatal pathway, cognitive and visual dysfunction can occur in early stages of the disease[2,23-25] and affect driving performance.[5-12] Within the PD group, decline in global cognitive function (MMSE, COGSTAT) predicted total error counts. However, the MMSE may not be practically useful in identifying drivers at risk for unsafe driving in a relatively well-educated cohort with mild to

**Table 5** Expected total of road safety errors as a function of UFOV and FVA in subjects with Parkinson disease

| | Predicted number of total road safety errors | | |
|---|---|---|---|
| FVA | UFOV = 525 | UFOV = 875 | UFOV = 1225 |
| −0.1 | 33.2 | 37.3 | 41.4 |
| 0.0 | 37.4 | 41.5 | 45.6 |
| 0.1 | 41.6 | 45.8 | 49.9 |

UFOV = useful field of view; FVA = far visual acuity.

moderate cognitive deficits like our drivers with PD (MMSE = 28.17 ± 1.80). While MMSE <24 is probably useful in identifying patients at increased risk for unsafe driving, MMSE scores of 24–30 probably do not effectively discriminate safe from unsafe drivers.[26]

The relationships between driving error counts and cognitive test scores help elucidate mechanisms of unsafe driving in PD. Declines in basic visual sensory abilities (FVA, CS), visual attention (UFOV), motion perception (SFM), and construction (CFT-COPY) and visual memory (CFT-Recall) were significant predictors of total errors counts, whereas motor or verbal measures were not. Far visual acuity and visual processing and attention were the most important predictors of total error counts. The literature on the predictive value of static visual acuity on driving performance and outcomes is mixed: for example, static visual acuity did not predict road performance in drivers with PD[8] or older drivers,[27] but significant associations with static visual acuity and driving difficulties in high-risk driving situations were found.[28] Our findings suggest that monitoring of static visual acuity in PD in addition to dynamic visual acuity and attention tests may be useful in predicting driver safety. Attentional decline is one the earliest and most prominent cognitive deficits in PD, associated with the involvement of the frontostriatal circuitry.[24,29] The association of visual perception and cognition with driving safety in PD is consistent with the primary visual nature of driving[18] and abilities affected in early PD.[2]

There may be several factors to explain the lack of association of motor dysfunction with road errors. For subject safety, we had the subjects only drive when they felt "on." This might have reduced the variability of motor scores contributing to lack of association with driving errors. Another factor could be that this road test did not include any sudden hazards when speed of behavior is critical. In an intersection incursion scenario in the driving simulator, we found that motor dysfunction was an important predictor of response time to a sudden hazard.[30]

Familiarity with the neighborhood mitigated against unsafe driving in this study. As the proportion of drivers familiar with the testing route differed between groups (controls 54%, PD 21%), we adjusted the group comparison of error counts for familiarity. This adjustment attenuated differences in several error categories, particularly "serious" errors, as well as errors for turns, speed control, parallel parking, and pulling away from the curb. Drivers with PD may be at increased risk for unsafe driving on unfamiliar roads, yet commit less safety errors in certain settings on known routes. This finding underscores the importance of using control groups in studies on driving in impaired populations and adjusting for familiarity when scoring road tests. Mitigation of some driving errors by familiarity with the driving environment raises a policy issue if driver testing for at-risk drivers is to be performed in both familiar and unfamiliar neighborhoods and suggests that graded licensure policies that allow driving in a familiar neighborhood can be considered for drivers with PD who have visual and cognitive dysfunction.

Our sample of patients with PD only included 15 (17.8%) women. This preponderance may reflect greater risk for PD in men[31] and VA recruitment sources. Gender may affect risk avoidance in older drivers[32] as well as topographic orientation strategies.[33] Also, the PD group was slightly less educated than controls, and less education was associated with higher rates of failure and marginal driving performance over time in another neurodegenerative disorder (Alzheimer disease).[34] However, statistical adjustment for age, education, and gender did not affect differences between the PD and control groups, except for a few infrequent error types.

Methodologic limitations include that our rater may have missed some errors due to not being in the vehicle during the drive despite video data provided by 4 cameras from different angles. Finally, we made many group comparisons and used many independent variables as predictors, which might have led to some spurious findings. However, we tried to keep our analyses well-focused by declaring the total safety error counts as our primary outcome measure a priori for between-group comparisons and prediction analyses (tables 4 and 5) and by using a composite measure of cognition (COGSTAT), in addition to individual cognitive tests, to give us a global test of whether cognitive variables were predictive of driving errors.

Our study gives potential hints on improving driving performance in PD. Building on the most important predictors of driving errors, we recommend that drivers with PD have their refractive errors corrected and wear their glasses as a simple and effective measure against impaired far visual acuity. Impaired visual speed of processing and attention as indexed by the UFOV test (a crash predictor in aging[35]) was another independent predictor of driving errors. Speed of processing and attention training using UFOV has been reported to benefit road performance in older drivers.[36] Future research to test the efficacy of speed of processing and attention training in rehabilitation of impaired drivers with PD can be considered. Our detailed observations on error categories can guide in developing PD driver education programs using classroom and road training, as done

for older drivers,[37] or driving simulator training to address specific problem areas in PD, such as lane observation, stop sign behavior, turns, and speed control, which can be potentially tailored for each individual.

A proportion of drivers with PD showed error counts similar to those of the controls, suggesting that diagnosis of PD alone is not sufficient to deem a driver unsafe and to restrict or revoke the driver's license. A standardized road test in conjunction with a detailed evaluation battery addressing different aspects of PD (e.g., cognitive, visual, motor) may help to identify drivers at risk for unsafe driving.

## AUTHOR CONTRIBUTIONS

Statistical analysis was conducted by Dr. Jeffrey D. Dawson, Elizabeth Dastrup, and Amy M. Johnson.

## DISCLOSURE

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