Impaired Visual Search in Drivers with Parkinson's Disease

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Objective: To assess the ability for visual search and recognition of roadside targets and safety errors during a landmark and traffic sign identification task in drivers with Parkinson's disease (PD).
Methods: Seventy-nine drivers with PD and 151neurologically normal older adults underwent a battery of visual, cognitive, and motor tests. The drivers were asked to report sightings of specific landmarks and traffic signs along a four-lane commercial strip during an experimental drive in an instrumented vehicle.
Results: The drivers with PD identified significantly fewer landmarks and traffic signs, and they committed more at-fault safety errors during the task than control subjects, even after adjusting for baseline errors. Within the PD group, the most important predictors of landmark and traffic sign identification rate were performances on Useful Field of View (visual speed of processing and attention) and Complex Figure Test-Copy (visuospatial abilities). Trail Making Test (B-A), a measure of cognitive flexibility independent of motor function, was the only independent predictor of at-fault safety errors in drivers with PD.
Interpretation: The cognitive and visual deficits associated with PD resulted in impaired visual search while driving, and the increased cognitive load during this task worsened their driving safety.

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Parkinson's disease (PD) is a multifaceted disorder with variable involvement of cognition, vision, sleep, autonomic function, and behavior, in addition to typical motor dysfunction.[1–3] One of the consequences of these widespread abnormalities in PD is impairment in driving safety,[4–17] as shown by epidemiological studies,[8] road tests,[5–7] and driving simulator experiments.[9,11,15,17] For example, PD affects visual processing and attention, as well as perception,[2,3,18] which may decrease the ability for efficient visual search and perception of complex scenes.[19]

Safe automobile driving requires a driver to perform multiple competing tasks and attend to a host of objects and ongoing events, whereas simultaneously monitoring traffic with central and peripheral vision to avoid roadway hazards.[20] Impairments in visual acuity and fields increase crashes and traffic violations.[21] However, drivers with neurological conditions that affect cognition may not perceive critical roadside information even in the absence of a measurable field defect on standard perimetry or diminished visual acuity.[20,22] Examples of such critical roadside information include landmarks (provide cues for navigation) and traffic signs (provide safety-relevant information).[22,23]

To address this real-world problem, we used an instrumented vehicle[22,24] to test the hypothesis that drivers with PD have impairments on a landmark and traffic sign identification task (LTIT).[22] We also tested whether the impaired drivers would commit more safety errors under the influence of the cognitive load imposed by the LTIT, placing them at greater risk for a potential crash. Finally, we tested whether LTIT performance and safety errors could be predicted by visual, cognitive, and motor measures sensitive to decline in PD.

Subjects and Methods

Subjects

The PD group consisted of 79 participants (64 men and 15 women) with mild-to-moderate disease severity (Hoehn and Yahr score = 2.2 ± 0.6; Table 1) who were recruited from the Movement Disorders Clinics at the Department of Neurology of the University of Iowa and the Veterans Affairs Medical Center (both in Iowa City, IA). Their mean ± stan-

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Table 1. Characteristics of Patients with Parkinson's Disease (n = 79)

Characteristics	Mean ± SD (median)
Age, years	66.0 ± 8.6 (66.0)
Disease duration, years	5.6 ± 5.0 (4.0)
Hoehn and Yahr stage (↓)	2.1 ± 0.7 (2.0)
UPDRS-ADL (↓)	11.6 ± 5.6 (11.0)
UPDRS-motor (↓)	24.1 ± 9.2 (24.0)
UPDRS-total (↓)	39.3 ± 15.5 (37.5)
Tapping speed (↑)	35.5 ± 6.1 (34.9)
7-meter walk (↑)	14.4 ± 3.9 (14.3)
Schwab-England score (↑)	83.9 ± 9.7 (90.0)
L-Dopa equivalent, mg/day	577 ± 585 (400)
MMSE score (↑)	28.3 ± 1.8 (29.0)
Epworth Sleepiness Scale score (↓)	9.6 ± 4.3 (10.0)

Upward arrow denotes higher score better; downward arrow denotes lower score better.

SD = standard deviation; UPDRS = Unified Parkinson's Disease Rating Scale; ADL = Activities of Daily Living; MMSE = Mini-Mental State Examination.

dard deviation (SD) (median) Mini-Mental State Examination score was 28.3 ± 1.8 (median, 29; range, 22–30; 2 subjects scored 22 and 1 scored 24).

All subjects were community-dwelling, independently living, and licensed, active drivers. The control subjects consisted of 151 neurologically normal elderly adults (75 men and 76 women), who were also licensed, active drivers. Driving exposure (ie, miles/week) for all participants was obtained from the Driver Habits Questionnaire,[25] and there was no significant difference between the groups (Table 2).

Inclusion criteria for subjects with idiopathic PD included that subjects must be currently active drivers with a valid State driver's license and driving experience of greater than 10 years. *Exclusion criteria* included cessation of driving before encounter; acute illness or active, confounding medical conditions such as vestibular disease; alcoholism or other forms of drug addiction (subjects with history of drug or alcohol dependency had to be in remission for at least 2 years); other neurological disease leading to dementia (eg, Alzheimer's disease, strokes) and motor dysfunction; secondary parkinsonism (eg, drug- induced); Parkinson-plus syndromes (eg, multiple system atrophy, progressive supranuclear palsy, corticobasal degeneration); concomitant treatment with centrally acting dopaminergic blockers within 180 days before baseline; treatment with any investigational drug within 60 days before baseline; major psychiatric disease not in remission; and diseases of the optic nerve, retina, or ocular media with corrected visual acuity less than 20/50.

Informed consent was obtained from all subjects in accord with institutional and federal guidelines for human subjects' safety and confidentiality.

Off-Road Testing Battery

All subjects with PD were tested during their "on" times. Subjects were allowed to take rest periods as needed. For all tests, raw scores were used for analysis. The battery methodology is explained in detail elsewhere in our recent work.[2] Table 2 shows the abilities tested by each measure and the direction of good performance. The Useful Field of View (UFOV) task (Visual Attention Analyzer; Visual Resources, Chicago, IL), a predictor for crashes in elderly adults and patients with Alzheimer's disease, measures speed (in milliseconds) of visual processing, divided attention, and selective attention. We used the sum of four subtests of the UFOV task in our analyses. Contrast sensitivity was assessed using the Pelli-Robson chart. The best corrected visual acuity was measured using the Early Treatment Diabetic Retinopathy Study (ETDRS) chart for far visual acuity and reduced Snellen chart for near visual acuity, both expressed as logMAR (logarithm of the minimum angle of resolution), with 0 representing 20/20 vision. Perception of three-dimensional structure-from-motion was tested using computer-generated animation sequences.

The Unified Parkinson's Disease Rating Scale and timed motor tests such as tapping and walking speed were administered to all subjects with PD (see Table 2).[26] Total daily L-dopa–equivalent amount (in milligrams) of antiparkinsonian medications was calculated using an established formula.[24] We also used Epworth Sleepiness Score and Geriatric Depression Scale (GDS) to assess nonmotor aspects of PD, and we used the Schwab-England Activities of Daily Living scale as a measure of overall disability associated with PD.[2]

Road Test

The experimental drive was conducted aboard an instrumented vehicle known as ARGOS (the Automobile for Research in Ergonomics and Safety), a mid-sized 1995 Ford Taurus station wagon with an automatic transmission and hidden instrumentation and sensors.[22,24] Experimental performance data (steering wheel position, normalized accelerator and brake pedal position, lateral and longitudinal acceleration, and vehicle speed) were digitized at 10Hz and reduced to means, SDs, or counts. Driver's lane tracking and driving behavior were recorded by videotape at 30 frames/sec using miniature lipstick-size cameras mounted unobtrusively within the vehicle. Digital driving data were superimposed on multiplex views using four channels of video. Control of speed[27] and of lane position[28] are critical aspects of driving, and unplanned lane deviations occur with degradation of driving performance.[29]

The road test in ARGOS was administered within 1 week of cognitive and visual testing, sometimes on the same day. Order of testing (cognitive and visual vs ARGOS) was random. Subjects were seated comfortably in the driver's seat. The experimenter sat in the front passenger seat to score the on-road performance and operate the dual controls, if needed. The experimenter gave standard instructions to the drivers on operating ARGOS. The experimental drive lasted approximately 45 minutes and started after the driver acclimated to ARGOS on a short test drive. The experimental drive consisted of "on-task" (eg, while performing LTIT) and "no-task" segments. Road testing was conducted only during the day (usually between 9:00 AM and 4:00 PM) on specific roads surrounding Iowa City and during the optimal motor response to antiparkinsonian medications ("on" time). Drivers were not tested in inclement weather that might cause poor visibility or road conditions. The assessment incorporated several essential maneuvers such as turns, stopping at a stop sign, and maintaining vehicle control.

Table 2. Comparison of Patients with Parkinson's Disease and Control Subjects Using Wilcoxon Rank-Sum Test

Category	Function	Measure	Parkinson's Disease (n = 79), Mean ± SD (median)	Control Subjects (n = 151), Mean ± SD (median)
Off-road battery				
Age			65.9 ± 8.6 (66.0)	65.3 ± 11.5 (68.0)
Education, years			14.8 ± 2.9 (13.0)[a]	15.6 ± 2.6 (16.0)
Driving exposure, miles/week			171.3 ± 172.3 (150)	156.7 ± 176.5 (100)
Basic visual sensory functions	Near visual acuity	Snellen Chart—logMAR (↓)	0.067 ± 0.070 (0.065)[b]	0.022 ± 0.041 (0.000)
	Far visual acuity	ETDRS Chart—logMAR (↓)	−0.028 ± 0154 (0.000)[b]	−0.085 ± 0.125 (−0.080)
	Contrast sensitivity	Pelli-Robson Chart (↑)	1.70 ± 0.15 (1.65)[b]	1.84 ± 0.15 (1.95)
Visual perception	Motion perception	SFM % (↓)	12.7 ± 5.2 (11.9)[c]	10.3 ± 2.8 (10.1)
	Attention	UFOV (↓)	884 ± 366 (825)[b]	635 ± 247 (611)
	Spatial perception	JLO (↑)	24.2 ± 4.4 (25.0)[c]	25.7 ± 3.9 (27.0)
Visual cognition	Construction	BLOCKS (↑)	33.2 ± 11.8 (30.0)[b]	39.9 ± 10.7 (40.0)
		CFT-Copy (↑)	26.9 ± 5.1 (28.0)[b]	31.8 ± 3.8 (33.0)
	Memory	CFT-Recall (↑)	13.2 ± 5.2 (13.5)[c]	15.8 ± 5.9 (15.0)
		BVRT-error (↓)	7.3 ± 4.1 (7.0)[b]	4.6 ± 2.6 (4.0)
Executive function	Set shifting	TMT(B-A) (↓)	83.8 ± 78.9 (59.8)[b]	46.5 ± 34.6 (37.5)
	Verbal fluency	COWA (↑)	34.2 ± 11.4 (33.0)[b]	39.1 ± 11.2 (40.0)
Verbal memory		AVLT-Recall (↑)	7.3 ± 3.6 (7.0)[b]	10.2 ± 3.2 (11.0)
Depression		GDS (↑)	5.9 ± 5.5 (5.0)[b]	3.3 ± 3.6 (2.0)
Balance		FR (↑)	11.4 ± 3.4 (11.0)[b]	13.4 ± 2.7 (13.5)

Upward arrow denotes higher score better; downward arrow denotes lower score better.

[a] $p < 0.05$; [b] $p < 0.001$; [c] $p < 0.01$.

SD = standard deviation; logMAR = logarithm of the minimum angle of resolution; 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; GDS = Geriatric Depression Scale; FR = Functional Reach.

Landmark and Traffic Sign Identification Task

LTIT[22] was administered as part of a sequence of on-the-road tasks in ARGOS. Drivers were asked to look for and report verbally on traffic signs and restaurants (a highly ubiquitous type of roadside landmark) along a 1-mile commercial segment of a four-lane divided highway approximately 1 minute before these stimuli started to appear. These targets were classified as high- or low-saliency stimuli based on ratings and detection rates of drivers tested in pilot studies. For example, a speed limit sign is a high-saliency stimulus detected by nearly all subjects, whereas a small and low mile marker is of lower saliency and is missed by some normal subjects. Likewise, a restaurant situated right on the road in its own building is a high-saliency stimulus, whereas a deli within a grocery store or a restaurant with a sign or building that can be seen afar, but is not on the route, is considered a lower saliency stimulus. There were a total of 16 road signs (11 high saliency) and 13 restaurants (6 high saliency) along the route, which also included 4 intersections with traffic lights. Intersections are associated with high information-processing demands[30–32] and increased risk for crashes.[33] Dependent measures were percentage of landmarks and traffic signs identified and number of at-fault safety errors such as erratic steering, lane deviation, shoulder incursion, stopping or slowing in unsafe circumstances, and unsafe intersection behavior during the task. We also counted at-fault safety errors during baseline segments (when no tasks were administered) of the drive and expressed them as number of errors per mile for comparison with the errors during LTIT. The LTIT performance was determined after review of the experiment forms filled out during the drive and subsequent final scoring during the video analysis of the task. The interrater reliability was more than 95%.

Statistical Analysis

We compared the PD and control groups with respect to demographic, visual, cognitive, and LTIT outcome measures using the Wilcoxon rank-sum test (Tables 2 and 3). Regression models were used to adjust the LTIT outcome comparisons for age, sex, visual acuity, and previous familiarity with the route ("yes" or "no" obtained by asking the driver about prior driving experience in and around Iowa City). We used the Wilcoxon rank-sum test to compare the within-group changes in error counts from baseline to LTIT segment between groups. We used Fisher's exact test to compare the proportion of drivers in each group who made at-fault safety errors.

To determine the univariate predictors of the LTIT outcome measures, we calculated Spearman correlation coefficients (Table 4) between the dependent measures (total landmark and traffic sign identification percentage and number of at-fault safety errors) and the scores on the cognitive, visual, and motor tests and measures of parkinsonism in the battery shown in Tables 1 and 2. Using the univariate predictors with $p \leq 0.1$, we performed multivariate analyses using forward stepwise linear regression to identify the independent predictors of total landmark and traffic sign identification percentage and using ordinal logistic regression for at-fault safety errors.

Table 3. Outcome Measures of the Landmark and Traffic Sign Identification Task in Parkinson's Disease and Normal Control Group, Compared Using Wilcoxon Rank-Sum Test

	Parkinson's Disease (n = 79), Mean ± SD (median)	Control Subjects (n = 151), Mean ± SD (median)
Landmark identification %		
All	33.0 ± 14.7 (30.8)[a]	44.6 ± 16.5 (46.2)
High saliency only	52.6 ± 20.8 (50.0)[a]	66.0 ± 21.2 (66.7)
Traffic sign identification %		
All	60.4 ± 19.5 (62.5)[a]	70.4 ± 17.6(75.0)
High saliency only	73.1 ± 22.1 (81.8)[a]	82.3 ± 17.8 (83.3)
Total LTIT identification %		
All	47.8 ± 13.1 (49.1)[a]	58.7 ± 13.8 (58.6)
High saliency only	65.9 ± 16.7 (70.6)[a]	76.8 ± 15.5 (77.8)
Number of at-fault safety errors		
During LTIT	1.97 ± 1.56 (2.00)[a]	0.45 ± 0.81 (0.00)
Baseline (per mile)	0.64 ± 0.40 (0.58)[a]	0.15 ± 0.18 (0.00)

The significant differences between the groups persisted after adjusting for familiarity with the region, far and near visual acuity, sex, driving exposure, and education.

[a] $p < 0.001$.

SD = standard deviation; LTIT = landmark and traffic sign identification task.

Table 4. Significant Differences between the Predictor and Dependent Variables within the Parkinson's Disease Group

Outcome	Predictors	Spearman Correlation Coefficients
Percentage identification of all targets	CFT-Copy	0.36[a,b]
	JLO	0.34[b]
	CS	0.33[b]
	UFOV	−0.30[a,b]
	BLOCKS	0.30[b]
	COWA	0.30[b]
	NVA	−0.27[c]
	FR	0.23[c]
Number of at-fault safety errors	CFT-Recall	−0.36[b]
	MMSE	−0.36[b]
	TMT(B-A)	0.35[a,b]
	CFT-Copy	−0.33[b]
	ESS	−0.24[c]
	FR	−0.24[c]
	COWA	−0.23[c]

[a]Independent predictors of respective outcomes after multivariate analysis.

[b] $p < 0.01$; [c] $p < 0.05$.

CFT = Complex Figure Test; JLO = Judgment of Line Orientation; CS = Contrast Sensitivity; UFOV = Useful Field of View; COWA = Controlled Oral Word Association; NVA = Near Visual Acuity; FR = Functional Reach; MMSE = Mini-Mental State Examination; TMT = Trail Making Test; ESS = Epworth Sleepiness Scale.

Results

Drivers with PD identified a significantly smaller percentage of restaurants and traffic signs and committed more at-fault safety errors during LTIT than the neurologically normal control subjects (see Table 3).

The difference between the groups persisted after adjusting for familiarity with the neighborhood, age, far and near visual acuity, and sex. The PD group also committed more at-fault safety errors at baseline (ie, when no secondary task such as LTIT was administered) segments of the drive (see Table 3). The number of at-fault safety errors increased from 0.64 ± 0.40 (mean ± SD) per mile at baseline to 1.97 ± 1.56 during LTIT in the PD group, whereas the error count only increased from 0.16 ± 0.18 to 0.45 ± 0.81 in the control group ($p < 0.0001$), indicating that the secondary task during driving (LTIT) led to a greater degradation of driving safety in drivers with PD. On a straight baseline segment of the drive with no task load, there was no significant difference between the groups in basic vehicular control as indexed by speed variability (mean SD of speed: PD group = 2.01 miles/hour, control group = 1.87 miles/hour; $p = 0.10$) and steering variability (mean SD of steering wheel position: PD group = 1.93 degrees, control group = 2.05 degrees; $p = 0.72$).

The proportion of subjects who made at least one at-fault safety error was higher in the PD group (83.1% in PD vs 29.8% in control group; $p < 0.0001$). Of the 83.1% of PD drivers with errors, 26% committed 1 error, 26% committed 2, 15.6% committed 3, 10.4% committed 4, 2.6% committed 5, 1.3% committed 6, and 1.3% committed 8. Among control subjects, 18.5% committed 1 error, 8.6% committed 2, 1.3% committed 3, and 1.3% committed 4. A significantly smaller proportion of drivers with PD were able to identify 60% or more of all targets (17.7% in PD vs 49.7% in control group) or high-saliency targets (68.4% in PD vs 90.1% in control group) (both $p < 0.0001$).

The PD group performed worse than the control group on neuropsychological and visual tests, showing mild cognitive impairment and visual perception and processing deficits (see Table 2). Measures of basic visual sensory functions (near visual acuity, contrast sensitivity), visual attention (UFOV), spatial perception (Judgment of Line Orientation), visuoconstructional abilities (Complex Figure Test-Copy, Block Design Test [BLOCKS]), nonverbal memory (Complex Figure Test-Recall), executive function (Trail Making Test [TMT] parts B and A [B-A], Controlled Oral Word Association), balance (Functional Reach), and overall cognitive function (Mini-Mental State Examination) correlated significantly (Spearman coefficient) with the outcome measures of the LTIT (see Table 4). There were no significant correlations between the total daily L-dopa–equivalent amount and LTIT outcomes. Spearman correlation coefficients between L-dopa–equivalent and identification percentage and safety errors were -0.1 ($p = 0.402$) and 0.1 ($p = 0.381$), respectively. Using regression methods for multivariate analyses, as described earlier, we identified TMT (B-A) as the only independent predictor of at-fault safety errors ($p < 0.01$) and UFOV and Complex Figure Test-Copy as independent predictors of total landmark and traffic sign identification percentage for all targets (high and low saliency together) (both $p < 0.05$).

Within the control group, measures of basic visual sensory functions (far visual acuity), visual attention (UFOV), spatial perception (Judgment of Line Orientation), visuoconstructional abilities (BLOCKS), verbal memory (Auditory Verbal Learning Test), level of depressive symptoms (GDS), and executive function (TMT [B-A]) correlated significantly (Spearman coefficient) with the percentage identification of all targets during LTIT (all $p < 0.01$ except for GDS and BLOCKS, where $p < 0.05$). However, only level of depressive symptoms GDS correlated with the number of safety errors in the control group ($p < 0.05$).

We did not find any significant Spearman correlations between at-fault safety errors and identification percentage of targets in either the PD or control group.

Discussion

The findings in this study support our hypothesis that drivers with PD would perform worse than neurologically normal drivers on a visual search and object recognition task while driving, and that this secondary task would degrade driving safety more in patients with PD compared with control subjects. These group differences could not be explained by familiarity with the region, far and near visual acuity, sex, driving exposure, and education differences between the groups. Performance on standardized tests of visual perception, visual processing and attention, executive functions, visuoconstructional abilities, and balance correlated with the LTIT outcome measures, consistent with its demands on multiple abilities that are impaired in PD. Lack of significant correlations between at-fault safety errors and identification rate of targets in the PD and control groups suggests that subjects were not prioritizing LTIT at the expense of driving.

The predictors of LTIT performance (see Table 4) in our study are consistent with cognitive processes required for normal visual search such as planning, visuospatial abilities, and attention.[34,35] We identified UFOV and Complex Figure Test-Copy as the most important predictors of landmark and traffic sign identification, indicating that visual attention and higher order visual processes such as visuoconstructional abilities are particularly important in visual search and object recognition. The LTIT requires executive control over attention to switch between the tasks of searching for landmarks and controlling the vehicle on the road. In this vein, regression modeling showed that the TMT (B-A), an index of cognitive flexibility to switch attention between two competing tasks independent of motor speed, was the most important predictor of driving safety during LTIT.

Within the control group, a similar pattern of correlations between target identification and cognitive/visual predictors was seen, as would be expected from the demands placed by the task. However, within the control group, only level of depressive symptoms correlated with at-fault safety errors. This observed lack of correlations for the safety errors within the control group could be due to the relatively small proportion of control subjects who committed safety errors and the limited range in the number of their errors. Because this study is primarily on driving risks in PD, we concentrate our discussion on PD.

Driving performance and safety errors in drivers with PD is an active research topic.[4–17] Our study examines the practical consequences of impaired visual search and object recognition during driving. These abilities have been shown to be impaired in PD in laboratory settings.[3,18,36] Inability to recognize traffic signs deprives the driver of key information on upcoming road hazards and safety regulations.[22] Missing a traffic sign may lead to potentially hazardous driving behaviors such as inappropriate speed, missing a turn, or noncompliance with various restrictions. Identification of landmarks is critical for successful navigation without getting lost,[23] which can increase driver anxiety due to uncertainty of location or attempts to read maps and further divert cognitive resources from key driving tasks in drivers with limited baseline reserves for visual perception and cognition.[24] The group difference in at-fault safety errors during LTIT persisted after controlling for difference in baseline errors, there was no difference in basic vehicle control measures on a straight baseline segment with no task load, and cog-

nitive flexibility was the most important predictor of at-fault safety errors, indicating that the cognitive burden of the visual search was the primary factor in worsening of the driving safety during this task in drivers with PD.

Limitations of the study include self-selection bias that may have underrepresented the drivers with worse impairments. Also, the task was perhaps too difficult (eg, large numbers of targets to identify in a short and busy highway segment), leading to errors in 30% of control drivers. However, there was no floor effect, and both groups could be well differentiated.

Although PD has been recognized primarily as a motor disorder, driving safety and vehicle control during performance of a secondary visual search and object recognition task was determined primarily by cognitive and visual aspects of the disease, consistent with other research on driving in PD.[5–7,12,17] This is not unusual given that impairments in working memory, attentional control, vision, and executive functions present early in the course of PD.[1–3,37–41] Although degeneration of the noradrenergic, serotoninergic, and cholinergic systems,[42] as well as early cortical Lewy bodies,[43] may also contribute to cognitive impairment in PD, these early cognitive abnormalities are primarily attributed to dopaminergic dysregulation of the frontostriatal circuitry.[44] Although loss of dopaminergic neurons in the nigrostriatal tract in PD most prominently affects dorsal putamen, leading to motor dysfunction, dopamine is also strongly depleted in the caudate nucleus,[45] which is associated with oculomotor, "prefrontal," and "limbic" circuits of the basal ganglia loops[46–48] and plays an important role in cognitive and behavioral aspects of the disease.[49–51] Thus, the abnormalities we observed are most likely associated with dysfunction of the caudate nucleus and its related circuits, rather than putamen, as also shown by lack of association of the LTIT outcomes with motor dysfunction in PD. Dopaminergic medication improves or impairs cognitive performance in PD depending on the nature of the task and the basal level of dopaminergic functioning in underlying corticostriatal circuitry.[52] This, in turn, has the potential to affect driving performance and safety. In our experiment, all PD subjects were tested in the "on" condition, and the total daily L-dopa–equivalent amount did not correlate with the performance on the LTIT task or safety errors, suggesting that dopaminergic medications may not have affected driving performance during the LTIT in our study.

A subset of drivers with PD performed well on LTIT, and some made no safety errors, suggesting that some individuals with PD remain good drivers. However, a substantial portion of PD patients experience development of progressive cognitive and visual deficits that can impair driving. The findings of this study and others[4–17] indicate that standardized neuropsychological and visual testing provide indices of key functional abilities in PD that are important for driving. Future research in this area must address the relation between relatively high-frequency low-severity safety errors, such as we measured in the instrumented vehicle, and low-frequency high-severity incidents, such as injurious crashes in epidemiological records.

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