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Impaired Curve Negotiation in Drivers with Parkinson's Disease

Parkinson Hastalığı Olan Sürücülerde Viraj Dönme Yetisinde Azalma

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ÖZET

Amaç: Bu çalışmada, Parkinson hastalığı olan sürücülerin viraj dönme yetisinin belirlenmesi amaçlanmıştır.

Hastalar ve Yöntem: Hafif-orta derecede Parkinson hastalığı olan 76 (65'i erkek, 11'i kadın) ve 51 (26'sı erkek, 25'i kadın) kontrol katılımcısına 37 millik bir otomobil kullanma simülasyonu sınavı sırasında 6 viraj dönüşü yaptırıldı. Katılanlara sürücü testi öncesinde motor, görsel, ve kognitif testler uygulandı.

Bulgular: Kontrollerle karşılaştırıldığında, Parkinson hastalığı olan sürücülerin, viraj ve referans düz yol bölümlerinde anlamlı derecede daha fazla lateral pozisyon standart sapması ve şerit uyum hatası yaptıkları, dolayısıyla daha düşük araç kontrolü ve sürüş güvenliği sergiledikleri bulundu. Parkinson hastalığı grubu motor, kognitif ve görsel yetiler konusunda da düşük performans gösterdi. Hareket algılanması, görsel-uzaysal yetiler, karar verme yetileri, postüral stabilite, genel kognitif durum ve günlük aktivitelerde bağımsızlığın azalması Parkinson hastalığı grubu sürücülerinde virajlarda araç kontrolü yetisindeki azalmayı öngören faktörler idi.

Yorum: Parkinson hastalığı olan sürücüler, kontrol grubuna kıyasla, virajlarda araç kontrolü ve sürüş güvenliği açısından daha düşük bir performans göstermektedir ve bu, motor fonksiyon bozukluğundan çok görsel algılama ve kognitif bozukluk nedeniyledir.

Anahtar Kelimeler: Parkinson hastalığı, otomobil sürücülüğü, kognisyon, görme.

ABSTRACT

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Objective: To assess the ability to negotiate curves in drivers with Parkinson's disease (PD).

Patients and Method: Licensed active drivers with mild-moderate PD (n= 76; 65 male, 11 female) and elderly controls (n= 51; 26 male, 25 female) drove on a simulated 2-lane rural highway in a high-fidelity simulator scenario in which the drivers had to negotiate 6 curves during a 37-mile drive. The participants underwent motor, cognitive, and visual testing before the simulator drive.

Results: Compared to controls, the drivers with PD had less vehicle control and driving safety, both on curves and straight baseline segments, as measured by significantly higher standard deviation of lateral position (SDLP) and lane violation counts. The PD group also scored lower on tests of motor, cognitive, and visual abilities. In the PD group, lower scores on tests of motion perception, visuospatial ability, executive function, postural instability, and general cognition, as well as a lower level of independence in daily activities predicted low vehicle control on curves.

Conclusion: Drivers with PD had less vehicle control and driving safety on curves compared to controls, which was associated primarily with impairments in visual perception and cognition, rather than motor function.

Key Words: Parkinson's disease, automobile driving, cognition, vision.

INTRODUCTION

Parkinson's disease (PD) is a relatively common, disabling progressive neurodegenerative disorder with a prevalence that increases with age (~0.3% among the general population and 3% among those over the age of 65 years) (1,2). The number of senior drivers is projected to increase 5-fold from 1986 to 2028 in North America, potentially increasing the number of drivers with PD (3). PD produces characteristic motor dysfunction, together with variable impairments in cognition, vision, sleep, autonomic function, and behavior, and increases the risk of dementia (1,4,5). Reliable epidemiological data on the risk of traffic accidents among PD patients does not exist; however, PD appears to be associated with a decrease in the frequency of driving and an increase in accidents, especially among those with severe motor and cognitive dysfunction, and excessive daytime sleepiness (6-8).

Standardized experimental road testing of PD patients show that while there are individuals within the normal range, drivers with PD as a group perform worse on various driving tasks and make more safety errors compared to drivers of similar age without neurological disease (9-12). Using an instrumented vehicle, we observed that, compared to elderly controls drivers with PD had poorer navigational skills and visual search abilities, and were affected more by audio-verbal distraction (13-15).

Driving simulator experiments show that drivers with PD have poorer vehicle control, increased sleepiness and weaving, and higher collision rates compared to controls (16-19). Drivers with PD were also shown to have impaired internal cuing and degradation of operational aspects of driving during a concurrent task (20,21). The addition of driving simulation assessment to a clinical screening battery increased the sensitivity and specificity of off-road testing in predicting the pass/fail status of drivers with PD on an official road test (22).

Curves, particularly on two-lane rural roads, are recognized as a significant safety issue and are associated with a 34% increase in accident frequency per sharp curve per kilometer (23). Negotiating curves requires that drivers anticipate the curve by adjusting their speed and lane position to accommodate the severity of the curve, which requires more attentional resources than driving on a straight section of road. In addition to explicit attentional cues (e.g., checking the speedometer), speed selection in curves depends on such implicit perceptual cues as edge rate information presented to the peripheral visual field (24). Possible causes for increased accident rates on curves include the inability to meet increased attentional demands due to fatigue or a medical condition, misperceptions of speed and curvature, and failure to maintain proper lateral position on the curve (23). Drivers with PD have impairment in visual perception, processing speed and attention, and executive and motor functions that can impair their ability to control their vehicle on a curve (4,5).

In the present study we examined driver vehicle control and driving safety on curves using a high-fidelity driving simulator, which provides optimal stimulus and response control in a challenging but safe environment (25-27). Our goals were to test the hypothesis that drivers with PD will have less vehicle control and more driving safety errors on curves compared to neurologically normal drivers, and to determine the cognitive, visual, and motor predictors of vehicle control on curves in the PD group (1,2).

PATIENTS and METHOD

Subjects

Drivers with PD were recruited from the Movement Disorders Clinics at the Department of Neurology, University of Iowa and the Veterans Affairs Medical Center, both in Iowa City. Consecutive PD patients were asked if they were licensed and driving. Those that were licensed and driving were offered the opportunity to participate in the study; approximately 75% (n= 88) chose to participate. Those that declined cited such reasons as lack of time or logistical concerns about transport. The control group consisted of 51 (26 male and 25 female) neurologically normal elderly respondents to a newspaper ad designed to recruit elderly drivers without neurological disease. All subjects were examined by a board certified neurologist with subspecialty training in PD (EYU) in order to confirm the diagnosis of PD and rule out neurological disease in the controls. All subjects were living independently in the community and were licensed active drivers.

Inclusion criteria: Subjects with idiopathic PD (PD group) or elderly individuals without neurological disease (control group) who were currently active drivers with a valid state driver's license and driving experience of more than 10 years.

Exclusion criteria: Cessation of driving prior to the study, acute illness or active confounding medical conditions, such as vestibular disease, alcoholism or other forms of drug addiction (subjects with a history of drug or alcohol dependency had to have been in remission for at least 2 years), other neurologic diseases leading to dementia (e.g. Alzheimer's disease, stroke) or motor dysfunction, secondary parkinsonism (e.g., drug-induced), Parkinson-plus syndromes (e.g. multiple system atrophy, progressive supranuclear palsy, corticobasal degeneration), concomitant treatment with centrally acting dopaminergic blockers within 180 days prior to baseline measurements, treatment with any investigational drug within 60 days prior to baseline measurements, major psychiatric diseases not in remission, diseases of the optic nerve, retina, or ocular media with corrected visual acuity < 20/50.

In order to maintain ecological validity, we performed all testing during the times when the subjects would normally feel ready to drive, i.e. during the "on" times, and we also allowed subjects to take rest periods as needed.

Informed consent was obtained according to the Declaration of Helsinki (BMJ 1991; 302: 1194), and institutional and federal guidelines for human subject safety and confidentiality.

Off-Road Testing Battery

The battery methodology is explained in detail in our recent work (4). Raw scores of all the tests were used for analysis. Table 1 shows the abilities tested by each measure and the direction of good performance. The Useful Field of View (UFOV) task (Visual Attention Analyzer Model 3000, Visual Resources Inc), a predictor for crashes in elderly and patients with AD, measures speed (in ms) of visual processing, divided attention, and selective attention. We used the sum of 4 UFOV task subtests in our analyses (4). Contrast sensitivity (CS) was assessed using the Pelli-Robson chart. Best-corrected visual acuity was measured using the ETDRS chart for far visual acuity (FVA) and the reduced Snellen chart for near visual acuity (NVA), both expressed as LogMAR (logarithm of the minimum angle of resolution), with 0 representing 20/20 vision. Perception of 3-dimensional structure-from-motion (SFM) was tested using computer-generated animation sequences (4).

The Unified Parkinson's Disease Rating Scale (UPDRS) and timed motor tests, such as finger tapping and walking speed, were administered to all subjects with PD (Table 1) (28). The total daily dose of levodopa or the equivalent amount (mg) of antiparkinsonian medications was calculated using an established formula (4). We also used the Epworth Sleepiness Score (ESS) and Geriatric

Table 1. Characteristics of patients with Parkinson's disease (n= 76) [Values represent mean ± SD (median), ↑= Higher score better, ↓= Lower score better].

Characteristics	Values
Age (years)	66.1 ± 9.1 (67.0)
Disease duration (years)	6.7 ± 5.3 (5.1)
Hoehn-Yahr stage (↓)	2.3 ± 0.7 (2.0)
UPDRS-ADL (↓)	11.8 ± 5.5 (12.5)
UPDRS-motor (↓)	25.4 ± 10.7 (25.3)
Schwab-England score (↑)	82.5 ± 16.0 (90.0)
Levodopa equivalent (mg/day)	611.7 ± 536 (405)

UPDRS: Unified Parkinson's Disease Rating Scale, ADL: Activities of Daily Living, MMSE: Mini Mental State Examination.

Depression Scale (GDS) to assess non-motor aspects of PD, and the Schwab-England Activities of Daily Living (SE-ADL) scale as a measure of overall disability associated with PD (4).

Driving Simulator Assessment

We studied the effects of visual and cognitive impairment in drivers with PD on their ability to avoid a collision with a suddenly incurring vehicle at an intersection under strictly controlled conditions in the synthetic environment provided by a SIREN (Simulator for Interdisciplinary Research in Ergonomics and Neuroscience) driving simulator (29,30). Driving simulation offers several advantages over the use of driving records and state road tests in the assessment of driver fitness. Simulators provide a good means of replicating road conditions under which driver decisions are made, and simulations are safe, without the associated safety risks of the road or test track.

Our SIREN high-fidelity driving simulator creates an immersive, real-time virtual environment for assessing at-risk drivers in a medical setting (29,30). SIREN comprises a 1994 GM Saturn, embedded electronic sensors, miniature video cameras for recording driver performance, a sound system and surrounding screens (150° forward FOV, 50° rear FOV), 4 LCD projectors with image generators, an integrated host computer, and another computer for scenario design, control, and data collection. A tile-based scenario development tool (DriveSafety, Salt Lake City, UT) allows us to select from multiple road types and to populate roadways with different vehicles that interact with the driver and each other, according to experimental needs.

Experimental performance data were collected digitally at 30 Hz and were reduced to means, standard deviations, or counts for each virtual road segment. Simulator output included steering wheel position (in degrees), normalized accelerator and brake position (i.e., scale of pedal depression from 0%-100%), speed (mph), and other variables, such as position of the car in the lane, and longitudinal and lateral acceleration. Driving performance was captured at 30 Hz using miniature cameras to record the scene observed by the driver and provided a backup record of each driver's performance and lane tracking. Synchronization of the digital and video data facilitated the inspection of artifacts and allowed for review of potential driver safety errors.

A warm-up and training phase lasting about 5 min preceded the experimental drive and was sufficient for adapting to the vehicle controls (31). A research assistant familiarized the drivers with the vehicle controls. A simulator operator communicated with the drivers by intercom to monitor for signs of discomfort or fatigue. Prior to beginning the experiment, each driver was familiarized with the simulator by driving on a simulated 2-lane highway.

Each subject drove approximately 37 miles on a simulated rural 2-lane highway (speed limit 55 mph) with interactive traffic. The driver had to negotiate 6 simple horizontal curves with a 600-m radius of curvature, representative of real-world curves typically encountered by the drivers (32). One-third of the drive took place in bright day light conditions and the remainder in fog with diminished visibility. Various scenarios to test different aspects of driving were also interspersed throughout the drive; however, no secondary tasks were administered on curves or designated straight baseline segments. The subjects were given a simulator adaptation questionnaire upon completing the drive (33).

Statistical Analysis

The standard deviation of lateral position (SDLP), number of lane violations, SD of steering wheel position (steering variability), SD of speed (speed variability), and the percentage of car volume outside the lane during each segment were obtained as dependent measures of driving performance.

We compared the PD and control groups with respect to demographic, visual, and cognitive parameters using the Wilcoxon rank sum test. Driving outcome measures were analyzed by fitting linear mixed models to unstructured correlation matrices, and age, education, gender, and visibility (daylight vs. fog) were included in the model. The 3 left hand curves in the fog section were averaged and treated as 1 curve to balance curve direction for analyses, because direction of curve can influence vehicle control (20).

To determine the univariate predictors of the impact of curves on PD patient driving performance, we calculated Spearman's correlation coefficients between the SDLP and lane violation counts, as well as the change in SDLP and lane violations from straight to curved segments; scores for the cognitive, visual, and motor measures are shown in Table 1 and Table 2. Using the univariate predictors with $p \geq 0.1$, we performed multivariate analyses (stepwise linear regression) to identify the independent predictors of these dependent measures.

RESULTS

In all, 88 drivers with PD and 64 control drivers attempted the drive. The difference in the number of those that completed the drive in the 2 groups (11 drivers with PD and 13 control drivers could not finish the drive due to simulator discomfort) was not significant ($p= 0.26$). Based on the simulator adaptation questionnaire, there were no

Table 2. Comparison of patients with Parkinson's disease (n= 76) and controls (n= 51) using the Wilcoxon rank sum test [Values represent mean ± SD (median), ↑= Higher score better, ↓= Lower score better, * p < 0.05, ** p < 0.01, *** p< 0.001].

			PD	Controls
Off-Road Battery		Age	66.1 ± 9.1 (67.0)	64.0 ± 7.2 (61.0)
		Education (years)	14.6 ± 2.7 (14.0)***	16.4 ± 2.3 (17.0)
		Gender	65 male, 11 female***	26 male, 25 female
Category	**Function**	**Measure**		
Basic Visual	Near VA	Snellen Chart-logMAR (↓)	0.090 ± 0.092 (0.097)***	0.020 ± 0.051 (0.000)
Sensory	Far VA	ETDRS Chart-logMAR (↓)	–0.002 ± 0.107 (0.020)**	–0.054 ± 0.112 (–0.060)
Functions	CS	Pelli-Robson Chart (↑)	1.67 ± 0.18 (1.65)***	1.77 ± 0.21 (1.80)
Visual	Motion Perception	SFM % (↓)	12.0 ± 4.6 (11.9)**	9.8 ± 2.7 (9.6)
Perception	Attention	UFOV (↓)	846 ± 392 (759)***	518 ± 174 (535)
	Spatial Perception	JLO (↑)	23.9 ± 4.1 (25.0)***	27.2 ± 2.8 (28.0)
Visual	Construction	BLOCKS (↑)	32.2 ± 11.3 (32.5)***	41.6 ± 10.0 (42.0)
Cognition		CFT-COPY (↑)	25.9 ± 4.9 (26.0)***	30.2 ± 2.9 (31.0)
	Memory	CFT-RECALL (↑)	12.4 ± 5.3 (12.3)***	16.6 ± 6.1 (16.5)
		BVRT-error (↓)	7.1 ± 3.7 (7.0)***	3.5 ± 2.1 (3.0)
Executive	Set Shifting	TMT (B-A) (↓)	83.8 ± 70.8 (60.4)***	39.2 ± 24.0 (37.2)
Functions	Verbal Fluency	COWA (↑)	33.9 ± 9.8 (33.0)**	39.9 ± 11.9 (37.0)
Verbal Memory		AVLT-RECALL (↑)	7.6 ± 3.7 (7.0)***	10.3 ± 3.3 (11.0)
General Cognition		MMSE (↑)	28.2 ± 1.7 (28.0)***	29.3 ± 0.9 (29.0)
Depression		GDS (↓)	5.9 ± 5.6 (5.0)***	2.5 ± 2.4 (2.0)
Sleepiness		ESS (↓)	10.0 ± 4.4 (11.0)***	7.0 ± 3.3 (7.0)
Motor	Speed	Finger Tapping/20 s (↑)	34.5 ± 7.8 (34.0)***	50.2 ± 9.6 (48.6)
Function		7 m walk (s) (↓)	14.3 ± 4.6 (13.6)***	8.9 ± 1.4 (8.6)
	Balance	FR (inches) (↑)	10.9 ± 3.4 (10.9)***	12.9 ± 2.6 (13.0)

AVLT: Auditory Verbal Learning Test, BVRT: Benton Visual Retention Test, CFT: Complex Figure Test, COWA: Controlled Oral Word Association Test, CS: Contrast sensitivity, ESS: Epworth Sleepiness Scale, FVA: Far visual acuity, FR: Functional reach, GDS: Geriatric Depression Scale, JLO: Judgment of Line Orientation Test, MMSE: Mini Mental Status Examination; NVA: Near visual acuity, PD: Parkinson's disease, SFM: Structure from Motion Test, TMT: Trail Making Test; UFOV: Useful Field of View Task.

significant group differences among those that completed the simulated drive in terms of discomfort along 9 dimensions (body temperature increase, boredom, dizziness, eye strain, headache, light-headedness, nausea, nervousness, sleepiness), as measured on a scale of 1-7 (1= no discomfort; 7= extreme discomfort) ($p> 0.05$). One subject with PD was excluded from the analyses due to outlier values during driving on curves (33). The final analyses were based on 76 drivers with PD and 51 control drivers. Exclusion of 1 PD patient did not lead to changes in the direction or significance of the group comparisons and within PD predictions.

The drivers with PD had mild-moderate disease severity (Table 1). The PD group was less educated and contained more males than the control group (Table 2). The PD group scored lower on neuropsychological and visual tests, showing mild cognitive and visual impairment (Table 2). Consistent with their disease status, drivers with PD had lower performance on motor tests.

Compared to the controls, drivers with PD has less vehicle control, and were less safe on both curves and straight baseline segments than the controls, as determined by significantly higher SDLP and lane violation counts, respectively (Table 3). There were no significant group differences in all other vehicle control measures (Table 3). All the results in Table 3 were adjusted for age, education, gender, and visibility status (fog vs. daylight).

Vehicle control (SDLP) and driving safety errors (lane violation counts) declined from straight baseline to curved segments within each group (after adjusting for age, education, and gender of subjects, as well as visibility conditions of the segment), as manifested by increased SDLP values and lane violation counts ($p< 0.001$). The increase in SDLP was significantly higher in the control group than in the PD group; however, there was no group difference in change of lane violation counts.

SDLP and lane violation counts on curves in the PD group correlated (Spearman's coefficients) with various measures of cognition, vision, and severity of PD (Table 4). According to multivariate analysis, the most important predictors of increased SDLP were decreased visuospatial constructional abilities (CFT-COPY), decreased verbal fluency and executive functions (COWA), and a reduced level of independence (Schwab-England score). These 3 measures were also the most important predictors of increased lane violations on curves in the PD group, along with a low score for general cognition (MMSE) (Table 4).

The increase in SDLP from straight baseline to curved segments in the PD group correlated (Spearman's coefficients) with SFM ($rho= 0.35$, $p< 0.01$), UFOV ($rho= 0.23$, $p< 0.1$) and FR ($rho= -0.23$, $p< 0.05$). Using regression methods for multivariate analyses we identified SFM and UFOV as the most important predictors of increased SDLP.

Table 3. Comparison of driving measures between the PD (n= 76) and control (n= 51) groups on straights and curves, adjusted for age, education, gender, and visibility status (fog vs. daylight) [Values represent mean ± SD (median)].

	Segment	PD	Controls	p
Gender		11 female, 65 male	25 female, 26 male	< 0.001
Age		66.10 ± 9.07 (67.00)	64.04 ± 7.16 (61.00)	0.175
Standard Deviation of Lane Position (SDLP)	Straight	0.298 ± 0.102 (0.277)	0.213 ± 0.070 (0.204)	< 0.0001
	Curves	0.373 ± 0.086 (0.362)	0.320 ± 0.061 (0.327)	0.0075
Lane violations	Straight	0.553 ± 0.989 (0)	0.108 ± 0.270 (0)	0.0030
	Curves	1.740 ± 1.542 (1.333)	1.158 ± 0.935 (1)	0.0506
% of volume outside the lane	Straight	0.541 ± 2.878 (0)	0.068 ± 0.279 (0)	0.3518
	Curves	2.194 ± 4.467 (1.004)	1.028 ± 1.540 (0.366)	0.2332
Speed	Straight	56.49 ± 6.12 (55.69)	54.63 ± 3.63 (55.43)	0.2357
	Curves	54.25 ± 5.92 (54.34)	51.87 ± 4.90 (53.02)	0.1938
Speed variability	Straight	1.395 ±1.010 (1.186)	1.755 ±1.039 (1.539)	0.2244
	Curves	1.773 ± 1.251 (1.361)	2.164 ± 1.251 (1.789)	0.7168
Steering degree	Straight	2.205 ± 0.051 (2.202)	2.199 ± 0.038 (2.201)	0.3202
	Curves	2.166 ± 0.167 (2.174)	2.209 ± 0.146 (2.220)	0.3797
Steering variability	Straight	2.000 ± 1.363 (1.824)	1.582 ± 0.833 (1.386)	0.2583
	Curves	4.093 ± 1.214 (3.814)	3.902 ± 0.683 (3.763)	0.3052

Table 4. Spearman's correlation coefficients between vehicle control on curves and measures of cognition, vision, motor function, and parkinsonism within the PD group (# p< 0.1, * p< 0.05, ** p< 0.01, *** p< 0.001. Bold values indicate the jointly most important predictors of the outcomes according to multivariate model selection).

Category	Function	Measure	SDLP	Lane Violations
Basic Visual	Near VA	Snellen Chart-logMAR (↓)	–0.03	–0.04
Sensory	Far VA	ETDRS Chart-logMAR (↓)	–0.03	0.03
Functions	CS	Pelli-Robson Chart (↑)	–0.21#	–0.18
Visual	Motion perception	SFM % (↓)	0.28*	0.32**
Perception	Attention	UFOV (↓)	0.18	0.22#
	Spatial perception	JLO (↑)	–0.23#	–0.23*
Visual Cognition	Construction	BLOCKS (↑)	–0.28*	–0.29*
		CFT-COPY (↑)	–0.35**	–0.40***
	Memory	CFT-RECALL (↑)	–0.27*	–0.29*
		BVRT-error (↓)	0.21#	0.18
Executive Functions	Set Shifting	TMT (B-A) (↓)	0.25*	0.27*
	Verbal Fluency	COWA (↑)	–0.24*	–0.20#
Verbal Memory		AVLT-RECALL (↑)	–0.10	–0.17
General	Cognition	MMSE (↑)	–0.30**	–0.40***
Depression		GDS (↓)	0.20 #	0.24*
Sleepiness		ESS (↓)	0.08	–0.02
Motor	Speed	Finger Tapping/20 s (↑)	–0.16	–0.11
Function		7 m walk (s) (↓)	0.14	0.04
	Balance	FR (inches) (↑)	–0.14	–0.09
Indices of		Disease duration (years)	0.24*	0.26*
Parkinson's		Hoehn-Yahr stage (↓)	0.23*	0.29*
Disease		UPDRS-ADL (↓)	0.21#	0.14
severity		UPDRS-motor (↓)	0.17	0.20#
		Schwab-England score (↑)	–0.31**	–0.28*
		Levodopa equivalent mg/day (↓)	0.15	0.25*

AVLT: Auditory Verbal Learning Test; BVRT: Benton Visual Retention Test, CFT: Complex Figure Test, COWA: Controlled Oral Word Association Test; CS: Contrast sensitivity, ESS: Epworth Sleepiness Scale, FVA: Far visual acuity, FR: Functional reach, GDS: Geriatric Depression Scale, JLO: Judgment of Line Orientation Test, MMSE: Mini Mental Status Examination, NVA: Near visual acuity, PD: Parkinson's disease, SFM: Structure from Motion Test, TMT: Trail Making Test, UFOV: Useful Field of View Task.

Using a similar approach for lane violation counts, the increase in lane violation counts from straight baseline to curved segments in the PD group correlated (Spearman's coefficients) with MMSE (rho= 0.24, p< 0.05) and JLO (rho= 0.21, p < 0.1).

DISCUSSION

The findings of the present study support the hypothesis that drivers with PD have more difficulty than neurologically normal drivers negotiating curves, as shown by poorer vehicle control (increased SDLP) and more driving safety errors (lane violation counts). The predictors of increased SDLP and lane violation counts on curves in the PD group included lower scores on measures of visual perception (motion perception-SFM, spatial perception-JLO), visual cognition (visuospatial constructional abilities-CFT-COPY and BLOCKS, and memory- CFT-RECALL), executive functions [set shifting-TMT (B-A), COWA], general cognition (MMSE), low mood (GDS), and indices of increased disease severity, such as higher Hoehn-Yahr stage, increased disease duration, more medication use (total levodopa equivalent), and less independence (Schwab-England scale). The increase in SDLP and error counts from straight segments to curved segments was predicted by measures of visual perception (SFM, JLO, and UFOV), cognition (MMSE), and postural instability (FR).

These predictors show that impairment in visual abilities, such as perception of motion and spatial orienta-

tion, executive functions (monitoring self-performance and adjusting), and general cognitive state are more important than motor impairment in PD (e.g. tremor and bradykinesia, which could also affect steering or speed selection) for adjustment of lane position while negotiating curves. The finding that, primarily, lower cognition and vision performance rather than motor function (motor UPDRS score, tapping and walking speed) predicted lower driving ability in PD is consistent with our previous results and those of other researchers (9-22,34). Postural instability (FR), the only significant motor predictor, according to our multivariate analyses, is also thought to be associated with poor cognition (4). Although PD has been recognized primarily as a motor disorder due to degeneration of the dopaminergic nigrostriatal pathway, cognitive dysfunction (associated with the central cholinergic system, early cortical Lewy bodies, and dopaminergic dysregulation of the frontostriatal circuitry) occurs early in the course of the disease and in mild-moderate PD patients these could be the cause of reduced visual perception and cognition while driving (4,37-39).

SDLP and lane violation counts increased significantly from straight segments to curves in both of the study groups. Drivers with PD also had lower performance on straight segments. Although there was no significant difference in the increase in driving safety errors from straight to curved segments between the PD drivers and controls, SDLP increased significantly more in the control group. This SDLP increase in the controls, relative to the PD group, without a similar increase in lane violation counts suggests that the controls (who had a much lower SDLP at baseline straight segments) were relaxed about vehicle control on curves without having additional driving safety errors.

As in our previous reports, a proportion of drivers with PD were able to drive without any vehicle control problems on curves, suggesting that a diagnosis of PD alone is not sufficient to deem a driver unsafe. A detailed evaluation battery that addresses different aspects of PD (e.g. cognitive, visual, and motor) may help to identify drivers at risk of unsafe driving (13-15,19).

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REFERENCES

1. *Lang AE, Lozano AM. Parkinson's disease. First of two parts. N Engl J Med 1998;339:1044-53.*
2. *Hughes TA, Ross HF, Mindham RH, Spokes EG. Mortality in Parkinson's disease and its association with dementia and depression. Acta Neurol Scand 2004;110:118-23.*
3. *Hopkins RW, Kilik L, Day DJ, Rows C, Tseng H. Driving and dementia in Ontario: A quantitative assessment of the problem. Can J Psychiatry 2004;49:434-8.*
4. *Uc EY, Rizzo M, Anderson SW, Qian S, Rodnitzky RL, Dawson JD. Visual dysfunction in Parkinson disease without dementia. Neurology 2005;65:1907-13.*
5. *Bodis-Wollner I. Neuropsychological and perceptual defects in Parkinson's disease. Parkinsonism Relat Disord 2003;9(Suppl 2):83-9.*
6. *Homann CN, Suppan K, Homann B, Crevenna R, Ivanic G, Ruzicka E. Driving in Parkinson's disease-a health hazard? J Neuro 2003;250:1439-46.*
7. *Dubinsky RM, Gray C, Husted D, Busenbark K, Vetere-Overfield B, Wiltfong D, et al. Driving in Parkinson's disease. Neurology 1991;41:517-20.*
8. *Meindorfner C, Körner Y, Möller JC, Stiasny-Kolster K, Oertel WH, Krüger HP. Driving in Parkinson's disease: Mobility, accidents, and sudden onset of sleep at the wheel. Mov Disord 2005;20:832-42.*
9. *Heikkila VM, Turkka J, Korpelainen J, Kallanranta T, Summala H. Decreased driving ability in people with Parkinson's disease. J Neurol Neurosurg Psychiatry 1998;64:325-30.*
10. *Wood JM, Worringham C, Kerr G, Mallon K, Silburn P. Quantitative assessment of driving performance in Parkinson's disease. J Neurol Neurosurg Psychiatry 2005;76:176-80.*
11. *Worringham CJ, Wood JM, Kerr GK, Silburn PA. Predictors of driving assessment outcome in Parkinson's disease. Mov Disord 2006; 21:230-5.*
12. *Amick MM, Grace J, Ott BR. Visual and cognitive predictors of driving safety in Parkinson's disease patients. Arch Clin Neuropsychol 2007;22:957-67.*
13. *Uc EY, Rizzo M, Anderson SW, Sparks JD, Rodnitzky RL, Dawson JD. Impaired navigation in drivers with Parkinson's disease. Brain 2007;130:2433-40.*
14. *Uc EY, Rizzo M, Anderson SW, Sparks JD, Rodnitzky RL, Dawson JD. Impaired visual search in drivers with Parkinson's disease. Ann Neurol 2006;60:407-13.*
15. *Uc EY, Rizzo M, Anderson SW, Sparks JD, Rodnitzky RL, Dawson JD. Driving with distraction in Parkinson disease. Neurology 2006;67:1774-80.*
16. *Madeley P, Hulley JL, Wildgust H, Mindham RN. Parkinson's disease and driving ability. J Neurol Neurosurg Psychiatry 1990;53:580-2.*
17. *Möller JC, Stiasny K, Hargutt V, Cassel W, Tietze H, Peter JH, et al. Evaluation of sleep and driving performance in six patients with Parkinson's disease reporting sudden onset of sleep under dopaminergic medication: A pilot study. Mov Disord 2002;17:474-81.*
18. *Zesiewicz TA, Cimino CR, Malek AR, Gardner N, Leaverton PL, Dunne PB, et al. Driving safety in Parkinson's disease. Neurology 2002;59:1787-8.*

19. *Uc EY, Rizzo M, Sparks JD, et al. Increased crash risk in drivers with Parkinson's disease under low visual contrast lighting conditions. Neurology 2007;68(Suppl):208.*
20. *Stolwyk RJ, Triggs TJ, Charlton JL, Iansek R, Bradshaw JL. Impact of internal versus external cueing on driving performance in people with Parkinson's disease. Mov Disord 2005;20:846-57.*
21. *Stolwyk RJ, Triggs TJ, Charlton JL, Moss S, Iansek R, Bradshaw JL. Effect of a concurrent task on driving performance in people with Parkinson's disease. Mov Disord 2006;21:2096-100.*
22. *Devos H, Vandenberghe W, Nieuwboer A, Tant M, Baten G, De Weerdt W. Predictors of fitness to drive in people with Parkinson disease. Neurology 2007;69:1434-41.*
23. *Charlton SG. The role of attention in horizontal curves: A comparison of advance warning, delineation, and road marking treatments. Accid Anal Prev 2007;*
24. *Charlton SG. Perceptual and attentional effects on drivers' speed selection at curves. Accid Anal Prev 2004;36:877-84.*
25. *Reinach SJ, Rizzo M, McGehee DV. Driving with Alzheimer disease: The anatomy of a crash. Alzheimer Dis Assoc Disord 1997;11(Suppl 1):21-7.*
26. *Rizzo M, Reinach S, McGehee D, Dawson J. Simulated car crashes and crash predictors in drivers with Alzheimer disease. Arch Neurol 1997;54:545-51.*
27. *Rizzo M, McGehee DV, Dawson JD, Anderson SN. Simulated car crashes at intersections in drivers with Alzheimer disease. Alzheimer Dis Assoc Disord 2001;15:10-20.*
28. *Defer GL, Widner H, Marie RM, Remy P, Levivier M. Core assessment program for surgical interventional therapies in Parkinson's disease (CAPSIT-PD). Mov Disord 1999;14:572-84.*
29. *Uc EY, Rizzo M, Anderson SW, Shi Q, Dawson JD. Unsafe rear-end collision avoidance in Alzheimer's disease. J Neurol Sci 2006;251:35-43.*
30. *Rizzo M, Jermeland J, Severson J. Instrumented Vehicles and Driving Simulators. In: Ball K, Wahl HW (eds). Driving in Old Age: Use of Technology to Promote Independence 2002:291-6.*
31. *McGehee DV, Lee JD, Rizzo M, et al. Quantitative analysis of Steering Adaptation on a High Performance Fixed-Base Driving Simulator. Transportation Research Part F: Traffic Psychology and Behavior.: Elsevier Science Ltd., 2004.*
32. *American Association of State Highway and Transportation Officials (AASHTO). A Policy on Geometric Design of Highways and Streets. 4th ed. 2001.*
33. *Rizzo M, Sheffield RA, Stierman L, et al. Demographic and driving performance factors in simulator adaptation syndrome. Proceedings of the Second International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design. 2003;201-8.*
34. *Stolwyk RJ, Charlton JL, Triggs TJ, Iansek R, Bradshaw JL. Neuropsychological function and driving ability in people with Parkinson's disease. J Clin Exp Neuropsychol 2006;28:898-913.*
35. *Aarsland D, Andersen K, Larsen JP, Lolk A, Krangh-Sorensen P. Prevalence and characteristics of dementia in Parkinson disease: An 8-year prospective study. Arch Neurol 2003;60:387-92.*
36. *Cools R, Stefanova E, Barker RA, Robbin TW, Owen AM. Dopaminergic modulation of high-level cognition in Parkinson's disease: The role of the prefrontal cortex revealed by PET. Brain 2002;125:584-94.*
37. *Cooper JA, Sagar HJ, Jordan N, Harvey NS, Sullivan EV. Cognitive impairment in early, untreated Parkinson's disease and its relationship to motor disability. Brain 1991;114(Pt 5): 2095-122.*
38. *Brown RG, Marsden CD. Internal versus external cues and the control of attention in Parkinson's disease. Brain 1988; 111(Pt 2):323-45.*
39. *Woodward TS, Bub DN, Hunter MA. Task switching deficits associated with Parkinson's disease reflect depleted attentional resources. Neuropsychologia 2002;40:1948-55.*

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