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Visual and cognitive predictors of driving safety in Parkinson's disease patients

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Abstract

This study assessed the clinical utility of contrast sensitivity (CS) relative to attention, executive function, and visuospatial abilities for predicting driving safety in participants with Parkinson's disease (PD). Twenty-five, non-demented PD patients completed measures of contrast sensitivity, visuospatial skills, executive functions, and attention. All PD participants also underwent a formal on-road driving evaluation. Of the 25 participants, 11 received a marginal or unsafe rating on the road test. Poorer driving performance was associated with worse performance on measures of CS, visuospatial constructions, set shifting, and attention. While impaired driving was associated with a range of cognitive and visual abilities, only a composite measure of executive functioning and visuospatial abilities, and not CS or attentional skills, predicted driving performance. These findings suggest that neuropsychological tests, which are multifactorial in nature and require visual perception and visual spatial judgments are the most useful screening measures for hazardous driving in PD patients.

Keywords

Contrast sensitivity; Executive function; Visuospatial; Activities of daily living

1. Introduction

There is converging evidence that individuals with Parkinson's disease (PD) are at increased risk for hazardous driving. Drivers over the age of 65 experience a higher annual fatality rate per mile driven than all age groups except individuals aged 25 and younger (NHTSA, 2000). Impaired driving may be more pervasive in PD, a neurodegenerative illness with onset typically in later life. In fact, in some countries, a physician's note is required for PD patients to renew their drivers' licenses (reviewed in Worringham, Wood, Kerr, & Silburn, 2006). A recent survey of over 6000 individuals with PD found that 15% of respondents reported involvement in a motor vehicle accident and 11% reported causing an accident in the past 5 years (Meindorfner et al., 2005). Compared to control participants PD patients commit more driving errors (Stolwyk, Charlton, Triggs, Iansek, & Bradshaw, 2006) and have more collisions (Zesiewicz et al., 2002) on simulated driving tasks. On-road driving assessments

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also indicate that PD patients perform more poorly compared to their age-matched counterparts. Grace et al. (2005) observed that during an on-road driving evaluation PD patients, compared to a control group, less frequently checked their blind spots when merging with traffic, changing lanes, or backing out of a space. Heikkilä, Turkka, Korpelainen, Kallanranta, and Summala (1998) also reported that during an on-road evaluation, PD participants committed more faults (errors that could lead to danger) and offences (serious infringements of traffic regulations) compared to the control group. Since some PD patients appear to have poorer driving skills compared to the general population, it is important to identify predictors of driving safety in this group.

The cardinal features of Parkinson's disease involve motor dysfunction, however, severity of motor impairment does not consistently relate to driving safety. The findings from previous studies have been mixed with some reporting an association between severity of the disease and driving safety (Wood, Worringham, Kerr, Mallon, & Silburn, 2005; Radford, Lincoln, & Lennox, 2004; Zesiewicz et al., 2002) while others report no association (Stolwyk et al., 2006; Heikkilä et al., 1998). In studies that have found a relation between the degree of motor impairment and driving performance, the measure of severity has varied (Hoehn and Yahr and Motor Scale of the UPDRS: Grace et al. and Zesiewicz et al., Webster's Rating Scale: Madeley, Hulley, Wildgust, & Mindham, 1990 and Radford et al., Disease duration: Wood et al. and Worringham et al.). In summary, no reliable measure of motor symptom severity consistently relates to driving skills in these studies.

Non-motor symptoms of Parkinson's disease also may be predictors of driving safety. For example, excessive daytime sleepiness (EDS) is commonly reported by PD patients and between 3.8% and 22.6% of PD respondents indicated falling asleep while behind the wheel of a car (Ondo et al., 2001; Hobson et al., 2002). An association between EDS and performance on a standardized road test was not supported (Amick, D'Abreu, Moro-de-Casillas, Chou, & Ott, 2007), although the presence of the driving instructor may have functioned to keep PD drivers more alert, as participants were aware that falling asleep could cause them to fail the road test.

By contrast, performance on neuropsychological tasks has been found to be associated with driving skills measured with a standardized road test. Previous studies indicate that performance on tasks that are multifactorial and require visually mediated executive functions and visual spatial skills are related to driving performance (Stolwyk et al., 2006; Worringham et al., 2006; Grace et al., 2005; Radford et al., 2004; Zesiewicz et al., 2002; Heikkilä et al., 1998). These findings are similar to the results of other studies conducted with healthy aging subjects. Specifically, the useful field of view (UFOV), a multifactorial measure of visual attention has been found to be a strong predictor of driving skills in the healthy elderly (Owsley, 1994). The UFOV, however, may be limited when used with neurological populations, as many patients are unable to complete this lengthy and difficult attentional task (Whelihan, DiCarlo, & Paul, 2005 Duchek, Hunt, Ball, Buckles, & Morris, 1998) and no difference in road test performance was found between patients with Alzheimer's disease (AD) who failed portions of the UFOV compared to AD patients who completed all the sections (Whelihan et al.).

It is possible that the previously observed association between visually mediated neuropsychological tasks and driving safety is due to an underlying deficit in basic visual functioning. Changes in basic visual functioning occur frequently in patients with PD. A common change in basic visual functioning among PD patients is decreased contrast sensitivity (CS) (Bodis-Wollner et al., 1987). CS is a measure of how faded a figure can be before it is indistinguishable from the background. CS deficits are due to the neuropathology of PD and do not reflect a normal aging process. Reduced availability of dopamine, which characterizes PD, likely accounts for changes in CS because medication state (on versus off) alters CS (Bodis-Wollner et al.). It has been proposed that CS deficits are due to the disruption of retinal functioning because there are cells within the retina which use dopamine for transmission (Parkinson, 1989) and a dopamine reducing agent applied to the retina produces CS impairments typical of PD patients (Bodis-Wollner & Tzelepi, 1998). Furthermore, autopsy of PD patients reveals reduced dopamine levels within the retina (Nguyen-Legros, Harnois, DiPaolo, & Simon, 1993).

CS is a fundamental aspect of visual processing necessary for performing multifactorial visual tasks including driving. CS deficits in PD patients are severe enough to influence performance on a task of visual cognition (Amick, Cronin-Golomb, & Gilmore, 2003). In other populations (Alzheimer's disease and healthy older adults) CS has been found to be an important predictor of driving errors during an actual road test (Uc, Rizzo, Anderson, Shi, & Dawson, 2004). PD related changes in CS could account for the previous findings that visually mediated neuropsychological tasks are the best predictors of driving safety. In sum, visual abilities are affected by PD and visual dysfunction may account for compromised performance on visually mediated tasks such as driving.

The purpose of this study was to identify visual and neuropsychological predictors of driving safety in individuals with Parkinson's disease. It was hypothesized that measuring CS would increase the amount of variance accounted for in road test scores beyond a composite measure of executive functions and visuospatial abilities. Additionally, CS was hypothesized to be more predictive of road test performance than the UFOV because fundamental changes in basic visual perception (CS) are expected to influence road test performance to a greater extent than decreased visual attention (UFOV).

2. Methods

2.1. Participants

Twenty-five participants with PD were included in this study (17 men, 8 women). Participants were recruited from an outpatient movement disorders center in Rhode Island. The study was approved by the Memorial Hospital of RI Committee on the Use of Human Subjects in Research. All participants gave written informed consent to participate in the study. Patients were diagnosed by a movement disorders specialist based on the following criteria: presence of two out of three cardinal manifestations (tremor, bradykinsesia, and rigidity) and a good response to dopaminergic medications. All assessments were conducted during the participant's self-reported optimal motor functioning to minimize the effects of motor and non-motor fluctuations on performance. Further, most participants completed the road test on a different day than the neuropsychological and vision testing to shorten the length of time spent at the hospital and also to minimize the chance of fluctuations. Safe and marginal drivers differed only on the demographic characteristics of mental status and UPDRS motor scores, summarized in Table 1. Although safe and marginal drivers differed in mental status, 3MS scores were not significantly correlated with errors on the driving test ($p > 0.05$). All of the participants indicated their ethnicity as Caucasian.

All participants had valid drivers' licenses and were driving on a regular basis. Exclusion criteria included neurological, physical, or psychiatric disorders other than Parkinson's disease that could have impacted driving skills. All participants had corrected binocular acuity ≤20/40. Eleven participants signed release forms allowing their optometrist/ ophthalmologist to complete a questionnaire about their visual health. Six optometrist/ ophthalmologist responded and all indicated that the patients' ophthalmologic health would not affect their performance on the study tasks. None of the individuals with PD met DSM IV-TR criteria for dementia and all had normal range Modified Mental Status Examination

Scores ≥83 (Teng & Chui, 1987). None of the individuals with PD showed significant signs of depression as measured by the Geriatric Depression Scale-Short Form, as all scores were ≤7. Disease severity as measured by the motor section of the UPDRS (Fahn et al., 1987) was measured within 1 month of the formal road test. Medications were converted into Llevodopa equivalent doses (Herzog et al., 2003). None of the participants were taking an anticholinergic. One person was treated with pergolide, four participants were treated with ropinerol, and 14 individuals were treated with pramipexole.

2.2. Procedures

2.2.1. Driving measures—A professional driving instructor administered the on-road driving test. The driving test was conducted during daylight hours in good weather conditions. Participants were taken out on the road test within approximately 2 weeks of their neuropsychological/visual functioning assessment. Participants completed the road test using the driving instructor's car, which was equipped with passenger side brakes. The instructor directed the participant along a predetermined route and observed their driving skills across a range of pre-identified driving maneuvers such as signaling, traveling speed, and checking blind spots. The road test was developed from the Washington University Road Test, a standardized driving measure with established reliability (Hunt et al., 1997). The WURT was adapted for use in Rhode Island such that drivers performed the same maneuvers in both tests and identical scoring procedures are used (previously described in Brown et al., 2005). Participants received a total error score, which was derived from the total number of errors committed on the road test. Scores could range from 0 (best performance) to 108 (worse performance). At the completion of the road test the driving instructor also gave a global rating of the participants driving skills (safe, marginal, or unsafe). The global rating and total error scores were significantly correlated ($r = 0.75$, $p < 0.001$).

2.2.1.1. Neuropsychological and visual measures: Participants were administered a brief battery of neuropsychological and visual measures to assess the association between cognitive dysfunction and CS impairment and driving performance. Based on previous findings, measures of executive functioning, visual spatial skills, and contrast sensitivity were selected (Grace et al., 2005; Amick et al., 2003).

2.2.1.2. Rey-osterreith complex figure test: (ROCF) (Stern et al., 1999), Copy of the figure was evaluated according to the Presence and Accuracy summary score (measuring visualspatial construction) and the Organization and Planning summary score (measuring executive functions) from the Boston Qualitative Scoring System (BQSS).

2.2.1.3. Trail making tests: (TMT) (Reitan & Wolfson, 1993). Trail A is a measure of speeded visual search. Trail B requires the additional executive ability of shifting between conceptual sets.

2.2.1.4. Useful field of view: (Ball & Roenker, 1998) The useful field of view version 1.0 was used. This computerized task is composed of three subtests. In part I participants are asked to determine if a car or truck is briefly presented in the center of a monitor. In part II the participant performs the same task as in part I and the additional demand is added of localizing a car simultaneously in the periphery. In part III the participant performs the same task as part II but distracters are present in the periphery making the localization task more difficult. For all three subtests the dependent measure was reaction time measured in milliseconds (ms).

2.2.1.5. Backwards visual masking: (Gilmore, Cronin-Golomb, Neargarder, & Morrison, 2005) Participants identified briefly presented letters followed by a masking stimulus. Prior to completing the task participants were adapted for 10 min to a darkened environment to ensure maximum performance. Letter stimuli were presented centrally on a computer monitor. Participants were seated approximately 16 in. from the monitor. Participants were asked to identify one of four letters (H, O, T or X), which were presented at 0.475 in. in height and subtended approximately 1.7° of visual angle. Letters were displayed within a box which served as a background and was held at a constant grey level. The luminance of the target letter was varied using an adaptive threshold procedure to establish a luminance level required to achieve 80% target identification accuracy (see Fig. 1).

The masking test is composed of four subtests. Within each subtest only the contrast of the target letter was adjusted. First, participants completed 20 practice trials to orient them to the task demands. During the practice subtest the letter (target) to be identified was presented at a maximum contrast of 91%. The second subtest served as practice to familiarize the participant with the threshold measurement procedures. In the third subtest the target contrast was adjusted to determine the contrast value needed for the participant to perform the task with 80% accuracy. The final subtest consisted of the participant completing 20 trials at their 80% accuracy contrast value to assess the reliability of the estimated contrast threshold. In this task the dependent measure is the contrast value needed to identify the target with 80% accuracy.

2.2.1.6. Functional acuity contrast test (FACT): (Ginsburg, 1996) Unlike the backwards visual masking task, the FACT is a static wall chart that measure CS to specific types of visual information (spatial frequencies). Participants viewed the wall chart binocularly from a distance of 10 feet. The chart displays a 9 × 5 array of circles and each circle is 1.7° of a visual angle. Each circle contains a grating. Standard procedures for performing the FACT were followed (see Ginsburg, 1996). Moving across a row from left to right, the contrast of each grating decreased monotonically in nine steps. Moving down a column, the gratings increased in spatial frequency (1.5, 3, 6, 12, and 18 cycles per degree). In each circle the gratings were oriented either to the left, to the right, or straight up and down. The participant's task was to indicate the orientation of the lines. A contrast threshold was determined for each spatial frequency by determining minimum contrast level for accurate identification of the orientation of each grating in a given row. In this task the dependent measures are the log contrast sensitivity values at each spatial frequency.

2.2.1.7. Pelli Robson: (Pelli, Robson, & Wilkins, 1988). Compared to the FACT the Pelli Robson does not measure CS at specific spatial frequencies but is a general and quicker to administer standardized tool for measuring CS. The chart consists of rows of letters that decrease in contrast. The letters are arranged in groups of three. In each successive group the contrast decreases. In this task the dependent measure is the threshold derived from the lowest contrast value at which two of the three letters are correctly reported.

2.2.2. Statistical plan—Mean group differences on the neuropsychological and certain visual tasks (backwards visual masking) were compared with *t*-tests. To examine the influence of CS upon driving safety, CS values from the FACT were submitted to a two-way mixed factorial analysis of variance (ANOVA) with a within subjects factor of CS at each of the spatial frequencies (1.5, 3, 6, 12, 18) and a between subjects factor of group (safe and marginal). Associations between errors on the road test and visual and neuropsychological performance were also examined with Pearson's correlations. Stepwise linear regression was used to determine the utility of visual and cognitive measures for predicting total number of errors on the road test. Discriminant function analysis was used to determine the classification accuracy of the neuropsychological measures. Associations between types of errors committed on the road test and performance on cognitive and visual measures were calculated with point biserial correlations.

3. Results

3.1. Road test performance

Forty-four percent of the participants received a marginal or unsafe rating of their driving abilities (1 unsafe, 10 marginal, and 14 safe). Since there was only one unsafe driver and their performance on visual and cognitive measures was similar to the marginal drivers, unsafe and marginal drivers were collapsed into one group (labeled marginal). The marginal group committed significantly more errors on the road test compared to the safe drivers (safe drivers; $M = 5.1$, S.D. = 3.0, marginal drivers; $M = 13.3$, S.D. = 4.9, $t(24) = -5.1$, $p = .001$).

The types of errors committed on the road test were compared in the safe and marginal groups. Only errors that were committed by >25% of the participants, in either group, were examined. Comparable to our previous studies, we selected a cutoff score of >25% in order to consolidate a large amount of data (60 possible maneuvers) and to identify meaningful differences between marginal and safe drivers. Low frequency errors (marginal group $n < 3$, safe group $n < 4$) were not reported. It is noted that total road test scores, includes all errors committed by the marginal and safe drivers. In this analysis each driving maneuver was considered equivalent. Participants either made an error on that maneuver or not. The driving errors were sorted into three categories (strategic, operational, and tactical) using a face validity approach (see Whithaar, Brouwer, & Van Zomeran, 2000; Grace et al., 2005; Stolwyk et al., 2006). Strategic errors reflect impairments in judgment, attention, and reasoning. Operational errors refer to disruptions in the timing aspects of driving, such as responding to the changing demands of the driving environment. Tactical errors reflect violations of the basic rules of the road. To summarize the qualitative findings shown in Table 2, it was observed that PD drivers committed the most errors in the tactical domain. Although the PD drivers committed few strategic and operational errors it appears that the marginal drivers showed poorer performance compared to the safe drivers in both the strategic and operational domains.

3.2. Cognitive and visual functioning

The neuropsychological, CS and UFOV performance of the safe and marginal drivers was compared with *t*-tests. Compared to the safe drivers, marginal drivers demonstrated significantly poorer performance on the trails B, ROCF/BQSS Presence/Accuracy summary score and the UFOV Part III (Table 3).

A two-way mixed ANOVA revealed that safe and marginal groups performed differently on the FACT. There was a significant effect of group ($F(1.23) = 5.15$, $p = .03$) because the marginal drivers had poorer contrast sensitivity (Fig. 2) relative to the safe drivers. There was no significant interaction of group × cycles per degree ($F(4.92) = 1.19$, p = ns).

Associations between errors on the road test and CS, neuropsychological, and UFOV performance were also examined with Pearson's correlations. There was a significant correlation between the road test total score and the UFOV part III ($r = 0.55$, $p < 0.01$), the ROCF BQSS Presence/Accuracy summary score ($r = -0.47$, $p < 0.05$), Trails B ($r = 0.49$, $p = 0.01$), and trails A ($r = 0.41$, $p < 0.05$). Poorer performance on the neuropsychological measures and a measure of visual attention, but not measures of CS, was associated with a greater numbers of errors on the road test.

To assess the predictive value of neuropsychological measures, contrast sensitivity scores, and UFOV performance, a composite measure for each domain was developed. *Z*-scores for each test based on the sample mean were calculated; then the average of the *z*-scores was computed for each domain to create a composite score. The composite score for the neuropsychological measures was derived from the averaged *z*-scores of the Rey-O Presence/Accuracy score, the Rey-O Organization/Planning score, and the trails A, and trails B scores. The composite contrast sensitivity score was derived from the averaged *z*-scores for each CS value for the FACT, the CS value for the Pelli-Robson, and the CS value for the backwards visual masking task. The UFOV composite score was derived from the averaged *z*-scores of each of the three subtests. All assumptions of multiple regression were supported. The dependent and independent variables had pearson correlation values $-0.40 < r < -0.56$. Multicolinearity was not present between the independent variables ($0.54 < r < 0.62$). All variables were normally distributed (Kolmogrov-Smirnoff, all values <0.17 and all ps ≥ 0.1). Finally, no outliers were identified using casewise diagnostics. Using stepwise linear regression only the composite measure of neuropsychological functioning significantly predicted total errors on the road test ($R^2 = 0.32$, $F = 10.7$, d.f. = 1, $p = 0.003$).

A discriminant function analysis revealed that the neuropsychological composite score significantly ($p = 0.01$) predicted group membership (safe or marginal). Safe drivers were correctly classified for 71.4% (10/14 participants) of the cases and marginal drivers were correctly classified for 72.7% of cases (8/11 participants) based on the composite neuropsychological score.

Using point biserial correlations the association between common types of driving errors and performance on the composite measures of CS, executive functions and visuospatial abilities, and the UFOV were examined (Table 2). In the domain of operational errors the following correlations were observed. Deficient awareness of how driving affects others was related to performance on neuropsychological composite measure and the UFOV composite score. Poor acceleration was associated with the averaged CS score, the averaged UFOV score, and the averaged neuropsychological score. None of the composite scores significantly correlated with any of the strategic errors. In the tactical domain the following associations were observed. Failure to check traffic when pulling away from a curb and failing to signal when pulling over to the curb was associated with the neuropsychological score. Signaling for a lane change was related to the average UFOV score.

4. Discussion

The findings from the current study indicate that traditional neuropsychological measures are the best predictor of driving safety. Specifically, we found that performance on trails B and copy of the ROCF differed between marginal and safe drivers. Longer completion times for trails B and inaccurate drawing of the ROCF were associated with more errors on the road test. A composite measure derived from the neuropsychological tasks was the only predictor of driving errors and the composite neuropsychological score correctly classified safe and marginal drivers for more than 70% of cases.

Consistent with these results, previous studies have also shown that neuropsychological measures that are visually mediated and multifactorial are predictive of on-road driving safety. Heikkilä et al. (1998) found in a sample of 20 male PD patients that time to perform a visual reasoning task, errors on a visual reasoning task, and time to recall visual material accounted for 62% of the variance of on-road test scores. Using a larger sample size ($n = 51$) Radford et al. (2004) found that performance on a visual cancellation test was an important predictor of road test performance. One limitation of the two previous studies is the fact that the neuropsychological measures selected are not commonly used clinically. By contrast, Worringham et al. (2006), like the current study, employed widely used neuropsychological tasks. In a sample of 25 PD patients the authors reported that performance on the Oral

Symbol Digit Modalities (speed of information processing), the Purdue Pegboard (motor speed), and the Pelli Robson (contrast sensitivity) correctly classified 68% of PD drivers. In a large sample of PD drivers ($n = 71$) a measure of executive functioning with the motor demands controlled for (reaction time for trails B—reaction time for trails A) was found to be the only predictor of errors during a live road test performed during a distracting task (Uc et al., 2006a).

Taken all together, these data suggest that neuropsychological measures that require rapid responding, visual spatial cognition, and executive functioning are most useful for distinguishing safe from marginal drivers. At this time, given the small sample sizes of previous studies, cut scores have not yet been determined for specific neuropsychological tasks to distinguish safe from unsafe driving. The findings from this study suggest that neuropsychological assessment is helpful for discriminating safe drivers, but almost 30% of our participants were misclassified. Currently, performance on certain neuropsychological measures may not clearly indicate which drivers are unsafe. Rather, neuropsychological assessment may be most helpful to inform clinical decisions as to which patients should undergo formal driving evaluations. Neuropsychological screening to determine which patients need the further procedure of undergoing a road test is helpful as it may limit the number of individuals who have to undergo this stressful and expensive examination.

Given that previous studies in PD patients have found that visually mediated neuropsychological measures were related to driving safety and visual impairments are prevalent in PD it was hypothesized that measures of basic visual perception (CS) would be related to driving skills. It was observed that scores on the FACT significantly differed between safe and marginal drivers. Additionally, compared to safe drivers, marginal drivers tended to require greater contrast levels to perform the backward visual masking task.

CS deficits are common in PD, can affect performance on higher-level tasks (Amick et al., 2003), and several studies including this report, have found a relation between CS and driving performance (Uc et al., 2006a,b). Our primary hypothesis that CS performance would predict driving performance was not supported. Despite the difference in the CS profiles of safe and marginal drivers, a composite measure of this visual ability did not predict driving safety. This is consistent with two previous reports, which found that CS performance, while correlated with measures of driving performance, was not predictive of driving errors (Uc et al., 2006a,b). There has been one report that the Pelli Robson, one of three measures, is a significant predictor of driving skills (Worringham et al., 2006). Yet the clinical utility of the Pelli Robson seems limited because only 68% of the PD patients were correctly classified in the discriminant function and the predictors were from highly diverse domains. A large study of AD patients and healthy older adults did observe that CS predicted errors on a road test (Uc et al., 2004) but differences in driving performance measures (their task required memorization of the route) could explain the discrepant findings. A larger study employing sensitive CS measures, such as those used in this study is necessary to properly evaluate the relative contribution of CS to driving safety in this population.

Compared to safe drivers, marginal drivers performed worse on the UFOV (part III) and poorer performance on part III of the UFOV was associated with more errors on the road test. A composite measure of UFOV scores, however, was not predictive of road test performance. A previous study using a newer version on the UFOV reported that safe and unsafe PD drivers did not perform differently on this task (Worringham et al., 2006). Uc et al. (2006b) have found that the performance on the UFOV is predictive of landmark and traffic sign identification but not at-fault safety errors. While the UFOV has been found to be predictive of driving safety in healthy elderly (Owsley, 1994), in PD patients this measure may not be as useful for determining driving safety. Our studies as well as others have observed that measures of neuropsychological function and to a lesser degree contrast sensitivity are associated with driving performance. Across studies the UFOV is less consistently associated with driving performance and may lack clinical utility in the PD population.

In the current study marginal drivers, unlike safe drivers, committed more frequent tactical errors such as clumsy lane changes (55%), turning into incorrect lanes (55%), not checking traffic when backing out (45%), and not signaling (45%) and these errors are committed by less than 20% of healthy elderly drivers (Grace et al., 2005). Marginal drivers also committed more frequent operational and strategic errors including decreased awareness of how their driving was affecting others (73%); they hesitated longer before making a turn (55%), did not accelerate to the proper speed (45%), and had lapses of concentration (45%). Previously it was observed that these types of errors occurred in less than 10% of elderly control participants (Grace et al.).

While other studies of live road test performance by PD patients have not use this classification system, it is clear that unsafe PD drivers have previously been found to commit both tactical and operational errors. Previously reported tactical errors include difficulty with visual scanning (Radford et al., 2004), turning left (Heikkilä et al., 1998), changing lanes, staying in the lane, monitoring blindspots, reversing car parking, and traffic light controlled intersections (Wood et al., 2005). While less frequently noted, other studies report that PD patients committed operational errors such as poor positioning of the car (Radford et al., 2004) and difficulty driving in traffic flow (Heikilla et al.). To summarize, PD patients commonly violate basic rules of the road and have difficulty monitoring the driving environment. Importantly these mistakes might be amendable to correction through interventions such as driving education or the use of adaptive equipment (to aid scanning and monitoring of blind spots).

Stolwyk et al. (2006) analyzed types of errors committed on a simulated driving task, using the same classification system as this study. They observed that PD patients more frequently committed tactical and operational compared to strategic errors and performance on neuropsychological measures was correlated with the tactical and operational errors (Stolywk et al.). The authors report that performance on measures of executive abilities and working memory are associated with tactical driving errors. By contrast, measures of basic visuo-perception and information processing speed were observed to relate to operational driving skills. We did not observe the same distinctions in our correlational analyses. In our study, CS, executive functioning, visual attention, and visuospatial abilities were associated with tactical and operational elements of driving. It should be recognized that Stolywk et al. used a driving simulator task and precisely measured participants' responses to variations in the difficulty of these tactical and operational maneuvers. The degree of experimental control in the study by Stolywk et al. may have isolated particular cognitive contributions to specific aspects of driving. In the current study, which used an on-road driving test, the method for assessing driving safety was less experimentally controlled but is believed to better resemble real life driving situations that PD patients will encounter.

At present time it is clear that the skills necessary to safely operate a motor vehicle are multifactorial. Driving safety could be determined with approximately 70% accuracy in PD patients based on neuropsychological performance. This suggests that screening visuospatial skills, executive functions, and possibly visual perception may help identify which patients should undergo a road test. Larger studies including longitudinal investigations are necessary to confirm the predictive utility of neuropsychological measures for determining PD driving safety.

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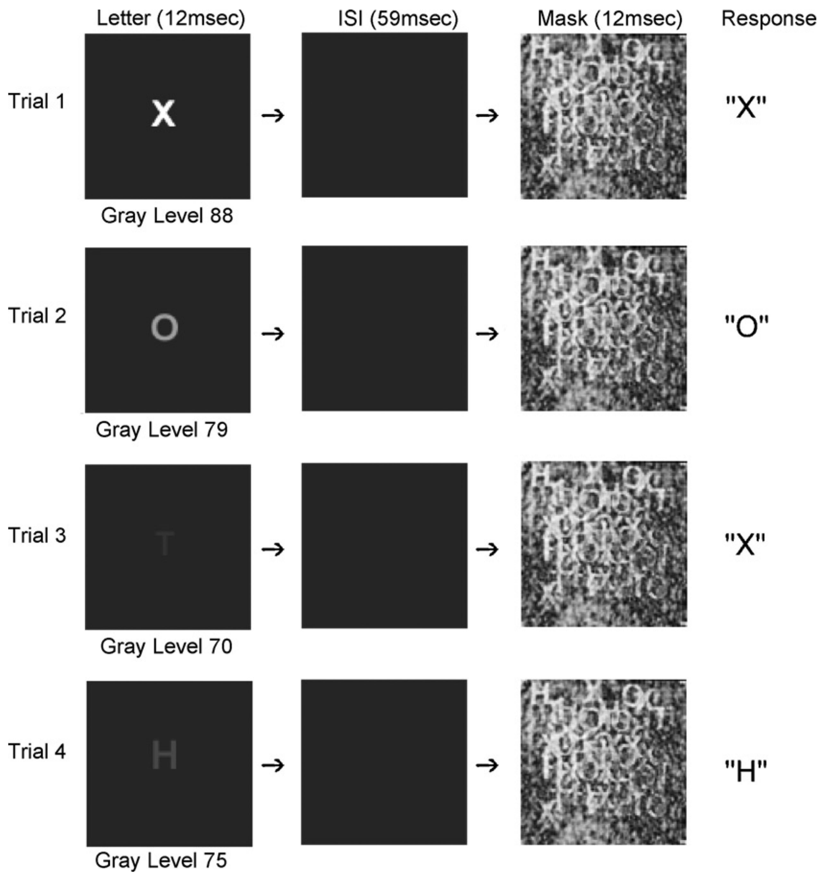

Fig. 1.

This is a schematic of the masking task. For each trial participants are shown a target letter (row one, column one), followed by a brief inter-stimulus-interval (row one, column two), followed by the mask (row one, column three). Participants then verbally indicate which of four letter options was just presented (row 1, column 4). If the participant is correct (as in trial 1) at the next trial the contrast of the target is reduced (row 2, column 1). This procedure continues until the participant commits and error (as in row 3, column 4) and then the contrast of the target letter is increased (row 4, column 1). This procedure continues until the accuracy criterion is reached.

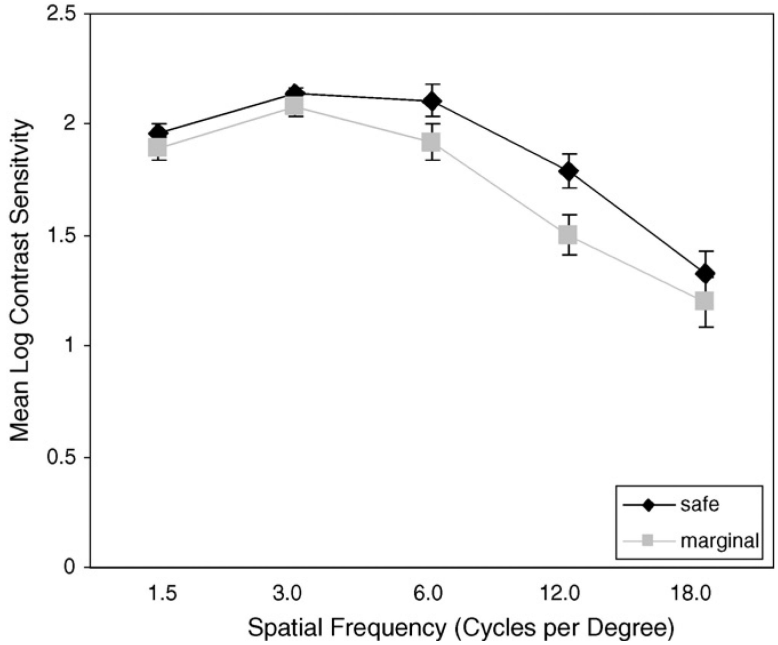

Fig. 2.

CS curves for safe and marginal drivers. The *y*-axis represents mean log CS values. The *x*-axis represents CPD. CS = contrast sensitivity, which is defined as the minimum difference between light and dark required to differentiate a figure from background. CPD = cycles per degree, which measures the frequency of spatial information contained in a visual scene.

Table 1

Participant characteristics

	Mean	S.D.	*t*-Value	*p*-Value	Eta squared
Age					
Safe	62.9	8.9	–1.0	0.33	0.04
Marginal	66.1	6.5			
Education					
Safe	16.2	2.5	1.4	0.18	0.08
Marginal	14.6	3.5			
Disease duration					
Safe	4.1	2.0	–1.0	0.33	0.04
Marginal	5.6	5.5			
UPDRS (motor only)					
Safe	15.0	8.7	–2.6	0.02	0.2
Marginal	25.5	11.5			
3MS					
Safe	97.4	1.9	2.6	0.02	0.2
Marginal	92.6	5.7			
Levodopa equivalent dose					
Safe	535.7	161.0	0.7	0.5	0.02
Marginal	477.3	270.5			
GDS					
Safe	2.2	2.1	0.04	0.9	<0.01
Marginal	2.2	2.5			
Weekly distance driven					
Safe	202.3	143.7	1.2	0.3	0.06
Marginal	141.8	102.3			
Years driving					
Safe	47.6	7.5	0.3	0.8	0.004
Marginal	46.5	10.0			

Table 2

Types of errors committed by PD drivers

	Marginal (n = 11) (%)	Safe (n = 14) (%)	NP	CS	UFOV
Operational					
Awareness of how driving affects others	73	0	–0.44*	–0.18	–0.44*
Prolonged hesitation before turning	55	14	–0.09	–0.22	–0.13
Accelerates to appropriate speed	45	7	–0.43*	–0.42*	–0.47*
Strategic					
Reasoning about turning left onto a one-way street	55	43	–0.05	0.07	–0.09
Lapses of concentration	45	7	–0.16	–0.37	–0.28
Tactical					
Checks traffic when pulling away from the curb	91	71	0.44*	–0.34	–0.28
Scanned environment for merging	73	57	–0.03	0.04	0.004
Smoothness of lane change	55	14	–0.27	–0.19	–0.09
Turns into appropriate lane	55	29	–0.21	0.06	–0.08
Checks blind spot for lane change	55	43	–0.04	–0.12	–0.16
Checks traffic before backing out	45	14	–0.05	–0.22	0.02
Signals for lane change	45	29	–0.36	–0.12	–0.42*
Signals to pull over to the curb	36	14	–0.49*	–0.22	–0.31
Comes to complete stop at four-way stop	36	29	–0.13	–0.31	–0.26

*Significant point biserial correlation ($p < .05$).

Table 3

Comparison of CS, UFOV, and Neuropsychological performance in safe and Marginal Drivers

	Safe drivers *n* = 14		**Marginal drivers *n* = 11**		***t*-Value**	***p*-Value**	**Eta square**
	Mean	**S.D.**	**Mean**	**S.D.**			
Backwards masking	41.8	15.9	52.0	9.1	–2.0	0.06	0.15
Pelli Robson	Range 1.1-1.7		Range 1.4–1.7		$\chi^2 = 7.3$	0.20	
UFOV I	45.5	63.2	73.6	63.1	–1.1	0.28	0.05
UFOV II	117.2	105.8	191.5	125.2	–1.6	0.12	0.10
UFOV III	246.8	99.9	349.6	124.6	–2.3	0.03	0.19
Trails A	30.4	6.1	36.9	10.6	–1.9	0.07	0.14
Trails B	68.5	22.4	109.5	60.4	–2.4	0.03	0.20
Rey-O Presence/Accuracy	6.4	1.6	5.9	1.4	2.6	0.02	0.23
Rey-O Organization/Planning	17.9	1.5	15.7	2.6	0.7	0.47	0.02