Relationships between Cognitive Functions and Driving Behavior in Parkinson's Disease

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Key Words

Parkinson's disease • Neuropsychology • Driving • Cognitive function • Executive function • Driving behavior • Road tests • Driving simulator

Abstract

Alterations in cognitive functions in Parkinson's disease (PD) have been reported even in mild stages of the disease. These functions may play a role in complex daily activities, such as driving. This article provides an overview on the relationships between cognitive functions and driving behavior in PD in driving simulator and on-road studies. The role of attention, executive functions, visual memory, visuospatial construction and information processing speed is discussed. In driving simulator studies, driving performances were correlated with several neuropsychological measures, especially those of Trail Making Test (TMT), Brixton and Symbol Digit Modalities Test. In on-road studies, TMT, Useful Field Of View and Block Design tests appear as good predictors of driving performances. Most of these tests are also relevant to driving in Alzheimer's disease and traumatic brain injury.

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Introduction

The frequency of Parkinson's disease (PD) is expected to increase dramatically in the coming decades due to aging of the population [1]. Although PD is typically identified as a motor disorder, it has also been well established that nonmotor symptoms such as visual, cognitive dysfunctions and increased daytime sleepiness may impact on driving [2–4]. These deficits can appear even in the early stages of the disease [5, 6]. The most frequently reported cognitive impairments occur in the domains of attention/executive functions, visuospatial abilities [7], psychomotor speed and memory [8]. These functions are all particularly important in novel, dynamic or demanding situations, and most driving scenarios fall into this category.

It is estimated that drivers with PD often continue to drive during the first decade of their illness [9–11]. Some studies have reported decreased driving performances in PD patients compared to controls on driving simulator tests [12–14] and road tests [15–18]. Patients commit more at-fault safety errors [16], especially in the categories of lane observance and stop signs. They also display diffi-

Fig. 1. Illustration of Michon's model and cognitive functions involved in driving.

culties in some driving situations, such as urban conditions [15] at intersections or at roundabouts [17]: patients hesitate longer before making a turn, do not accelerate to the proper speed and experience lapses of concentration. They have a decreased awareness of how their driving is affecting others [19] and drive more slowly with higher speed variability during distraction [10, 11].

Although many studies showed decreased driving performances in PD patients, there is no clear evidence on real risk of crashes in this population [20, 21]. Some authors have shown an increased crash rate in driving simulator studies [13, 22] or in retrospective studies, especially those in whom the disease is severe [23, 24]. However, these studies have methodological bias or limitations such as small sample or lack of control group. Conversely, a cross-sectional study including a population-based sample of 1051 drivers aged 65 years or more [25] showed that PD patients did not report more crashes than drivers without neurological diseases. Nevertheless, the sample size for PD was small. A recent prospective study on 106 PD drivers and 130 controls revealed no difference between groups in crash risk [21]. One explanation might be that patients would stop driving before having crashes [21]. Indeed, PD patients stopped driving earlier than controls [21]. Driving cessation is either decided by the drivers themselves [1], their family or their practitioners [26]. To better understand the reasons for driving cessation or increased crashes in PD, several groups investigated the factors that may contribute to poor driving performances [1, 16, 27, 28]. It appears that the role of cognitive factors in PD is a major issue and could be more crucial than motor, visual functions, daytime sleepiness and medication effects [11, 15, 17, 29, 30].

The present paper provides a narrative overview on the relationships between cognitive functions and driv-

ing behavior in PD. We first develop the theoretical basis of driving behavior and its relevance to PD. Then, we examine the correlations between neuropsychological performances and driving abilities in PD both in simulator and on-road studies. Finally, we briefly compare the main findings observed in PD with other neurological diseases, such as Alzheimer's disease (AD), traumatic brain injury or stroke. We conclude with some clinical recommendations and future research perspectives.

Theoretical Basis of Driving Behavior and Its Relevance to PD

Driving is a complex activity which requires various visual, motor and cognitive abilities. In most driving situations, the driver has to use perception, process information and to make a number of decisions very quickly. In order to understand driving activity better, Michon et al. [31] have distinguished three levels of driving behavior. Strategic level behaviors include actions such as choosing the route and time of travel. Tactical level behaviors involve actions such as adapting following distance and adjusting speed. Operational level behaviors include second-to-second driving behaviors such as maintaining lane position and reacting to obstacles. These operational behaviors are heavily time-pressured. As shown in figure 1, these levels imply several cognitive domains.

The Michon's model is relevant to PD. Indeed, literature shows that PD patients have difficulties in these three driving behavior levels. For strategical level, they have difficulties while performing a distraction or navigation task [10, 11]. Regarding tactical level, PD drivers have problems in reversing, negotiating traffic light con-

trolled intersections, adapting driving to changing road conditions or changing lane [12, 15, 17, 19]. As referred to operational level, patients have an increased driving reaction time, a delayed deceleration or difficulties in maintaining a constant lateral position [12, 14, 32–34].

Relationships between Cognitive Functions and Driving Behavior in PD

Most reports have compared PD patients' driving performances to those of matched healthy controls. Some studies are conducted on driving simulators, which involve tactical and operational level behaviors; other studies use instrumented vehicles in real on-road situations, which involve both of these levels but also strategic level behavior. In this type of experiment, PD patients are always evaluated while on medication, when they are feeling their best.

Studies on Driving Simulators

Approach using the driving simulator may offer the advantage of accurately assessing driving behavior in a controlled and reproducible environment. It provides a safe environment for the patient and the evaluator and great associations between simulator and on-road performance have been reported [35]. Table 1 summarizes studies focusing on the relationships between cognitive functions and driving behavior using driving simulator in PD patients. The four main research papers on this topic are those of Stolwyk et al. [12, 30, 33] and from our group [36].

In the three Stolwyk studies, the same population was used. Their first study examined the impact of cueing on driving behaviors around traffic signs and curves in PD [12]. In this experiment, the driver was warned of upcoming obstacles. Results showed that patients exhibited difficulties using internal cues (use of information previously memorized from the map) to regulate driving behavior around traffic signs and curves. Instead of using internal cues, PD drivers were more reliant on external cues (road signs which warn upcoming obstacles) to regulate driving behavior [12]. One of the possible explanations could be that internal guiding demands more attentional resources than external cues. This result suggests that external cues, such as driving assistance systems might be useful for PD drivers. Further research should consider these findings in the future.

The second research of Stolwyk et al. [30] investigated correlations between neuropsychological test performances and driving simulator behaviors. Authors showed

that the impairment of key executive skills (Trail Making Test-B (TMT-B) and Brixton) compromises tactical level driving behaviors in patients with PD. Moreover, an impairment of lower order cognitive skills such as information processing speed (Symbol Digit Modalities Test SDMT – oral version), attention to detail (picture completion task) and basic visuoperception (Judgement Line Orientation (JLO)) involves difficulties in driving behaviors at the operational level [30]. These authors recommend the TMT-B, SDMT and Brixton as potential screening tools for driving competency assessment in people with PD.

The third study of Stolwyk et al. [33] investigated the impact of a concurrent task on driving performance. Main results showed that patients, as controls adapted their driving behavior when the concurrent task was present. However, PD patients performed significantly less well the concurrent task than controls. As suggested by the authors, it is likely that PD drivers sacrificed concurrent task performance to maintain driving ability. Findings of these three studies support the hypothesis of decreased attentional resources in PD patients [10, 33]. However, PD drivers were able to maintain appropriate driving behavior especially in low or moderate attentional demanding conditions which is an important result for road safety.

Recently, low-level executive functions, particularly the updating of information in working memory and mental flexibility in patients with mild-to-moderate PD compared to controls have been investigated by our group both in neuropsychological and simulated driving contexts [36]. The main finding was an impairment of updating function in early stages of PD whereas there were no differences in flexibility tasks between the two groups. It also appeared that updating task on driving simulator have a greater impact on driving performances (mean speed and speed variability) for both groups, suggesting that updating task is more demanding than flexibility task. Another contribution of this study was to reveal the usefulness of TMT in PD driver assessment which is in accordance with many other studies [2, 10, 30, 37].

In summary, main findings of studies using driving simulator highlight potential tools for PD driver assessment. Among these tools, TMT, Brixton test and SDMT which assess executive functions and/or information processing speed are relevant.

On-Road Studies

Road studies are assumed to be the most ecological tests of driving competence. Six main experiments have

Table 1. Relationships between cognitive functions and driving behavior in PD: studies using driving simulator

Refer- ence	Participants/group size Main demographic and clinical characteristics of PD patients	Neuropsychological tests and their corresponding functions	Types of driving tasks	Driving variables	Main findings
12	18 PD patients and 18 controls matched for age, formal education, driving experience Age: 67.62 ± 6.53 Years of disease duration: 6.67 ± 4.21 UPDRS motor score: 11.67 ± 8.15		Participants navigated through different driving conditions where the opportunity to use internal and external cues was manipulated. Internal cue: participants drove on a familiar and memorized road sequence. External cue: participants saw arrow road signs before upcoming curves or a black diamond road sign before each traffic signal. 4 experimental conditions: internally guided driving possible, no external cues; internally guided driving possible, external cues; internally guided driving not possible, no external cues; internally guided driving not possible, external cues.	For traffic signal behaviors: Approach speed; deceleration point; stopping point. For curve behaviors: Mean speed; effect of curve; speed variance; mean lane position; lane position variance.	UPDRS motor scores, disease duration, and level of medication did not associate with any driving measures. Without external cues, controls could adjust mean curve speed according to internal cueing possibility, whereas participants with PD could not. Mean curve speed in controls was influenced less by external cues when internal cueing was possible, whereas participants with PD were equally influenced by external cues across conditions. Effects of curve curvature on speed variability were influenced more by internal cueing possibility in controls and by external cueing in PD patients.
30	Same population, same characteristics	MMSE: general cognitive status. Up and Go test: functional mobility measure. TMT-A: basic information processing/psychomotor speed. TMT-B: high-level information processing/working memory ability. SDMT: basic information processing speed. SRT: motor function. CRT: motor function. Brixton test: set formation/shifting ability. JLO: basic visuo-perceptual ability. Picture completion: visual attention. Digit span: information processing capacity. Block Design: high-level visuoconstructional ability.	Participants navigated on a two-lane open roadway in two driving scenarios: traffic signals and curves.	Same driving measures	For patients: Significant between-group differences in neuropsychological tests excepted for Brixton test, Digit span, Block Design. No significant correlation between driving measures and performances in: MMSE, Up and Go test, SRT, CRT, UPDRS motor and Digit span. Significant correlation between driving measures and performances of: TMT-A, SDMT, JLO, picture completion, Block Design, Brixton and TMT-B (these two last measures correlated most strongly and widely with driving measures). For controls: Significant correlation between driving measures and performances of: TMT-A, JLO, Block Design
33	Same population, same characteristics		Participants completed 20 concurrent task simulations and 20 nonconcurrent task simulations.	Same driving measures	Performances of the concurrent task were significantly reduced in people with PD compared to controls. The concurrent task had a significant effect on numerous driving performance measures, this effect was generally comparable between groups.

Table 1 (continued)

Refer- ence	Participants/group size Main demographic and clinical characteristics of PD patients	Neuropsychological tests and their corresponding functions	Types of driving tasks	Driving variables	Main findings
36	25 PD patients and 25 controls matched for sex, age, education level and driving experience Age: 65.4 ± 5.2 Years of disease duration: 6.4 ± 5.4 UPDRS motor score: 14.9 ± 5.2	TMT (B-A): global executive function. Stroop-test interference list: inhibition. BVRT: Visual memory. Digit span task: Short-term storage capacity. Baddeley's Working Memory digit- span task, single condition: maintenance of relevant information. N-back task: updating. Plus-minus task: mental flexibility. Stroop test, color denomination: information processing speed.	Updating task: Participants were asked to recall the last three road signs of each series while driving (free recall). They subsequently had to answer different questions about information given on the last three road signs (cued recall). Flexibility task: Participants were asked to state the shape of the road sign if it was on the right-hand side and the color of the road sign if it was on the left. Information processing task: Participants were asked to press the accelerator pedal, and to respond to the appearance of the brake lights of the car ahead, by braking as quickly as possible in two conditions: static and dynamic.	Mean speed Speed variability	An updating impairment was found in PD patients in the n-back and simulator tasks. No notable differences were observed between groups in the plus-minus task or in the simulator task evaluating flexibility. No significant differences were observed between groups in information processing speed tasks. TMT (B-A) accounted for 40.7% of the variation in PD drivers' simulator task updating score.

BVRT = Benton Visual Retention Test; CRT = choice reaction time; JLO = Judgement Line Orientation; MMSE = mini mental state examination; SDMT = Symbol Digit Modalities Test – oral ver-
sion; SRT = simple reaction time; TMT = Trail Making Test; UPDRS = Unified Parkinson's Disease Rating Scale.

investigated correlations between cognitive performanc-
es and driving abilities in real on-road situations in PD
patients compared to matched healthy controls [10, 11, 15,
16, 18, 19] (table 2). One of the purposes of these reports
was to find methods of assessing the driving ability of PD
patients.

In the Heikkila et al. [15] study, measures of labora-
tory tests correlated to a high degree with driving perfor-
mances in PD patients. These authors suggest that tests
of vigilance and concentration, visual perception, choice
reaction time and information processing in a complex
situation should be included in the assessment of PD
drivers [15]. In a larger sample, decline in visual attention
(Useful Field Of View (UFOV)), visual construction
(Block Design), visual memory and general cognition ap-
peared to be significant predictors of total error counts
within the PD group [16]. In the Worringham et al. [18]
study which investigated the predictors of driving in PD,
only 1 of 6 cognitive tests, the SDMT, correlated signifi-
cantly with the average driving safety score. This test,
performed verbally, was considered in this study as a
measure of short-term memory and attention switching.
Performances at this test were also significantly better for
those who passed than those who failed the on-road test
[18]. In another study, SDMT performance was also cor-
related with driving measures [38]. Amick et al. [19]
showed that neuropsychological composite score, consid-
ered as a measure of executive functions, is associated
with performances in the tactical domain. This is consis-
tent with the idea that key executive skills compromise
tactical driving behavior [30]. It has been suggested that
neuropsychological measures requiring rapid respond-
ing, visual spatial cognition and executive functioning
are most useful for distinguishing safe from marginal
drivers [19]. However, since no control group is available
in this latter study, it is not possible to determine which
neuropsychological tests can discriminate PD patients
from healthy control drivers [19].

As is well known, driving is an activity in which the
individual drives in a continually changing environment
while thinking or speaking at the same time. Other re-
search has also been conducted in order to investigate the
role of cognitive functions in driving activity while driv-
ers performed a secondary task. Uc et al. [10] showed that
PD patients responded more heterogeneously to distrac-
tion than controls. According to the authors, the associa-
tion of increased steering variability with better function
on cognitive, vision, and motor tests might represent, un-
der this experimental setting, a compensatory effort to
maintain vehicle control despite distraction. In addition,

Table 2. Relationships between cognitive functions and driving behavior in PD: on-road studies

Reference	Participants/group size Main demographic and clinical characteristics of PD patients	Neuropsychological tests and their corresponding functions ^a	Types of driving tasks	Driving variables	Main findings
15	20 PD patients and 20 age and sex matched healthy control subjects. Age: 59 ± 11 Years of disease duration: 5.6 ± 2.8 No UPDRS motor score.	CR and TT: visual perception. CR-vigilance: concentration. Correct reactions, decision time and motor time: choice reaction. CR, correct and within time responses, omitted stimuli, wrong responses: information processing.	Participants drove on road both in urban and rural surroundings on a standard and relatively difficult route. The route was designed to be sufficiently difficult.	Faults. Offenses: serious infringements of traffic regulations. Evaluation of driving ability carried out with a 10 point scale by the neurologist, psychologist, a vocational rehabilitation counsellor and the driving instructor.	Diseases indices (such as duration of disease, Hoehn and Yahr scale, and MMSE scale) did not show significant correlations with the result of driving test. According to the stepwise regression model, slowness of visual processing, a dose of levodopa and age explained 67 % of the variation in the faults in the driving test.
18	25 PD patients and 21 controls matched for age, formal education, driving experience. Age: 63.7 ± 6.8 Years of disease duration: 6.2 ± 4.6 UPDRS motor score: 27.4 ± 11.3	Cognitive tests: SDMT – oral version: short term memory and attention switching. TMT-A: rapid visual processing. TMT-B: working memory. Stroop test: inhibition. Motor tests: Aiming task: movement planning and execution process. Coincidence-anticipation: motor timing Purdue pegboard test: manual dexterity.	Participants drove on a 19.4 km inner-urban route.	Independent safety ratings were obtained from an occupational therapist and an accredited professional driving instructor. Both assessments used a 10-point scale. Scores of 5 or less indicated failure.	Age, contrast sensitivity (Pelli-Robson), the SDMT and the Purdue Pegboard test were significantly correlated with the average driving safety score and were also significantly better for those who passed than those who failed the on-road test. These variables (except age) were examined using discriminant function analysis. Prediction of failure was followed by an actual failure in 75% of controls, and approximately 90% of the PD cases, when time since diagnosis was included.
19	25 PD patients. No control group. Data not available for the entire group 14 safe drivers Age: 62.9 ± 8.9 Years of disease duration: 4.1 ± 2.0 UPDRS motor score: 15.0 ± 8.7 11 marginal drivers Age: 66.1 ± 6.5 Years of disease duration: 5.6 ± 5.5 UPDRS motor score: 25.5 ± 11.5	UFOV: visual attention. TMT-A: speeded visual search. TMT-B: speeded visual search and executive ability of shifting between conceptual sets. Rey-O presence/accuracy: visuospatial construction. UFOV composite measure ^b . Neuropsychological composite measure ^c – executive functions.	Participants drove along a pre-determined route including a range of pre-identified driving maneuvers.	Total error score, which was derived from the total number of errors committed on the road test. Global rating of the participants driving skills by the driving instructor (safe, marginal, or unsafe).	Marginal drivers demonstrated significantly poorer performance on the TMT-B, ROCF SCORE and UFOV part III compared to safe drivers. Using stepwise linear regression, only the composite measure of neuropsychological functioning significantly predicted total errors on the road test.

Table 2 (continued)

Refer- ence	Participants/group size Main demographic and clinical characteristics of PD patients	Neuropsychological tests and their corresponding functions ^a	Types of driving tasks	Driving variables	Main findings
10	71 PD patients and 147 elderly controls. Age: 66.0 ± 8.6 Years of disease duration: 5.3 ± 4.9 UPDRS motor score: 23.5 ± 7.9	Contrast sensitivity: visual functions. Visual acuity: visual functions. SFM: motion perception. JLO: spatial perception. UFOV: attention. BVRT: memory. CFT: construction. Blocks: construction. TMT (B-A): set shifting. COWA: verbal fluency.	Participants drove on a straightaway freeway segment with low traffic load during 45 min. The experimental drive consisted of 'on-task' (e.g., while performing PASAT) and 'no-task' segments.	At-fault safety errors. Measures of vehicle control: speed; speed variability; steering variability.	Larger proportions of drivers with PD showed either worsening or improvement in the driving safety errors in response to distraction. Impairments in cognitive flexibility, verbal and visual memory, visual perception, postural control, and excessive daytime sleepiness predicted worsening of safety errors and vehicular control due to distraction within the PD group. Within the PD group, the only independent predictor of committing more at-fault safety errors during distraction (adjusted for baseline error counts) was a decreased cognitive flexibility to switch attention between the two competing tasks, as measured by TMT (B-A). Both groups displayed increased steering variability during PASAT compared with the baseline segment. Increased steering variability during distraction correlated with younger age, better postural control, tapping speed, and cognitive flexibility, with baseline steering variability and postural control emerging as independent predictors.
11	77 PD patients and 152 neurologically normal elderly adults. Age: 65.9 ± 8.6 Years of disease duration: 5.7 ± 5.1 UPDRS motor score: 23.7 ± 8.7	Same battery than those used in Uc et al., 2006.	Participants drove across residential city streets, suburban commercial strips, rural two-lane highways and fourlane 65 mph speed limit freeway. Route-following (RFT) was tested as part a sequence of on-the-road tasks. Drivers were given verbal instructions to follow a route while the car was stopped and parked.	At-fault safety errors Navigational errors: incorrect turns; getting lost. Measures of vehicle control: speed; speed variability; steering variability.	Drivers with PD make more navigational errors than normal drivers on the road. PD patients make greater number of at-fault safety errors during the RFT, even after adjusting for baseline errors. Measures of verbal and visual memory (AVLT, CFT-Recall, BVRT), executive function (TMT (B-A), COWA), visual sensory abilities (Far Visual Acuity) and perception (JLO), visual attention (UFOV), visuomotor abilities (CFT-Copy, Blocks) and overall cognitive function (MMSE) correlated significantly with the RFT outcome measures. Height PD patients with no RFT impairments (number of incorrect turns, getting lost or at-fault safety errors all zero) scored better on TMT (B-A), Blocks and a higher level of education than other PD drivers.
16	84 PD patients and 182 controls. Age: 67.3 ± 7.68 Years of disease duration: 5.9 ± 5.0 UPDRS motor score: 24.1 ± 8.9	Same battery than those used in Uc et al., 2006.	Participants drove across residential city streets, suburban commercial strips, rural two-lane highways and fourlane 65 mph speed limit freeway.	Safety errors.	Declines in basic visual sensory abilities (Far visual acuity, CS), visual attention (UFOV), motion perception (SFM), and construction (CFT-Copy) and visual memory (CFT-Recall) were significant predictors of total error counts, whereas motor or verbal measures were not.

^a Only cognitive and motor tests are displayed in on-road studies. ^b The UFOV composite score was derived from the averaged z-scores of each of the three subtests. ^c 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 TMT-A, and TMT-B scores.

AVLT = Auditory Verbal Learning Test; CFT = Complex Figure Test; COWA = Controlled Oral Word Association; CR = correct responses; CS = contrast sensitivity; MMSE = mini mental state examination; PASAT = Paced Auditory Serial Addition Task; Rey-O = Rey-Osterreith Complex Figure Test; RFT = route following task; SDMT = Symbol Digit Modalities Test; SFM = structure from motion; TMT-A/B = Trail Making Test part A/part B; TT = total time; UFOV = useful field of view; UPDRS = Unified Parkinson's Disease Rating Scale.

the TMT (B–A) performance was the only independent predictor of safety errors during distraction. Accordingly, in another study performed by the same team, PD drivers with no impairments in Route Following Task scored better on TMT (B–A). These two on-road studies confirm the usefulness of TMT for clinicians to predict driving performances in PD drivers. Importantly, clinical indices such as disease duration, motor score or Hoehn et Yahr scale have not been shown as reliable predictors of driving performances in most studies suggesting that they cannot be used alone as relevant indicators of safe driving (table 2) [15, 17, 26, 39].

In summary, main findings of studies on-road suggest that TMT, SDMT, UFOV and Block Design tests are good predictors of driving or have strong correlations with driving performances in patients with PD.

Comparison with Other Neurological Diseases

The question that arises is the following: Are the neuropsychological tests used in PD drivers specific to this pathology or are they common to other neurological diseases?

First, we shall examine the results found in driving studies in patients with AD, which is a neurodegenerative disease as PD (for review, see [40]). While there is no consensus about real crash risk in PD, there is clear evidence that AD patients have an increased risk of crashes compared to age-matched controls [41]. Several studies attempted to determine the neuropsychological tests that predict unsafe driving in AD patients. For instance, Uc et al. [37] showed in 61 AD drivers and 115 elderly controls that unsafe outcomes were predicted by tests of visual perception (JLO, Complex Figure Test (CFT), Block Design), speed of processing and attention (UFOV), memory, visuospatial/constructional abilities (CFT-Copy CFT-Recall), mobility and executive functions (TMT-B). Interestingly, tests used to predict driving in AD patients are similar to those used in PD patients. However, AD patients exhibit severe deficits in all tests whereas PD patients with mild-to-moderate stages have more specific and discrete alterations especially in executive and visuospatial functions [8].

Second, in traumatic brain injury patients, the most important lesions are located in the frontal lobes, which are involved in executive functions. Additionally, driving difficulties in this population have been associated with impaired attention, concentration, processing speed, visual memory and visual-spatial skills (for review, see [42]). Accordingly, as in PD, TMT-B, SDMT or Block Design are reported as good predictors of unsafe driving in traumatic brain injured patients [42].

Third, in stroke patients, no uniform method exists to evaluate post-stroke patients' driving ability since more focal deficits are concerned. More than hemiplegia, visual performances are a major issue. This is particularly the case with homonymous visual field defects especially because many stroke patients are unaware of the field loss. Thus, the assessment of driving safety is significantly different in stroke compared to PD patients (for review, see [43]).

To summarize, similar neuropsychological tests may be used to assess driving ability in various neurological conditions. It is not surprising because of their multi-composite nature, as is the case for driving activity. This applies particularly for PD, AD and traumatic brain injury [40, 42, 44].

Conclusions

This review aimed to investigate cognitive predictors of driving ability in PD drivers. Although further work is required, it is an important goal to help clinicians or researchers to determine cognitive tests that could be used as a means of evaluating driving ability in PD patients and identify unsafe drivers.

Clinical Recommendations

The published evidence on driving performance in PD patients supports the following recommendations for PD driver assessment:

- First, assess main domains which can affect driving such as executive, visuospatial and information processing speed functions.
- Second, use a battery of neuropsychological tests which have been shown as the best predictors of driving performance in PD patients such as TMT, UFOV, SDMT – oral version and Brixton.
- Third, do not use clinical indices alone, such as duration of disease, Hoehn and Yahr scale and mini mental state examination scale as reliable indicators of driving [15, 39].

These recommendations are, however, not strong enough to provide for any of these neuropsychological tests a cut-off below which authorities would prevent PD patients from driving.

Future Research

As shown above, there is little literature about driving and PD compared with other neurological diseases such as AD or traumatic brain injury. Further research could be

addressed regarding crash risk and driving cessation in PD, and using naturalistic driving conditions to investigate the real road safety risk of this population. As outlined by Klimkeit et al. [39], a lot of work is needed to better advise health professionals. Additional research is also required to determine the degree of impairment for which drivers can be considered as unsafe. Furthermore, a cognitive training program involving executive, atten-

tional functions relevant to the driving activity could be worthwhile to rehabilitate PD patients with driving impairments.

Disclosure Statement

None of the authors have a conflict of interest.

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