Visual search during simulated driving in Parkinson's Disease

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Abstract

Patients with PD often exhibit difficulties with visual search that may impede their ability to recognize landmarks and cars while driving. The main objective of this study was to investigate visual search performances of both billboards and cars in patients with PD using a driving simulator. A second objective was to examine the role of cognitive functions in performing the visual search task while driving. Nineteen patients with PD (age: 68 ± 8yo, sex (Men/Women): 15/4) and 14 controls (age: 60 ± 11yo, sex: 7/7) first performed a battery of cognitive tests (e.g. MOntreal Cognitive Assessment (MOCA), Trail Making Test and Dot Cancellation test). They then drove in a simulator and were instructed to follow a lead vehicle while searching for billboards with the letter A (stationary target) or red cars (moving target) among other distractors. Accuracy and response times of visual search were the main outcome variables. Standard deviation of lateral position (SDLP) was the secondary outcome. During driving, patients were less accurate in identifying the targets, particularly for the stationary billboards located in the outer periphery. Within the group of patients, significant correlations were found between several measures of cognitive tests and simulator-based visual search accuracy. By contrast, only the score on the MOCA test correlated significantly with visual search accuracy in controls. Findings suggest that patients with PD have impaired visual search for stationary targets while driving a simulator, which is likely due to cognitive deficits. Future studies should be conducted in a larger sample size to determine whether a visual search task on a driving simulator may predict on-road driving performances.

Keywords: Parkinson’s disease; visual search task; driving; cognitive functions

Highlights:

- This research investigated visual search during driving a simulator in PD patients
- Patients experience difficulties with visual search skills
- Patients have difficulties to identify billboards in the outer periphery while driving
- This study highlights the major role of specific cognitive functions in PD drivers

1. Introduction

With an estimated seven to ten million people with Parkinson's disease (PD) worldwide, PD is the second most common neurodegenerative disease and the number of individuals with PD is expected to double by 2030 (Dorsey et al., 2007). Patients with PD may experience a range of cognitive and visual deficits, including deficits in visual search that may negatively affect activities of daily living, such as the ability to drive (Devos et al., 2013; Uc et al., 2006).

In visual search tasks, participants search for a target while ignoring irrelevant stimuli. The targets of interest can be either stationary or moving, while the background with irrelevant stimuli can be either stationary or moving as well. Previous studies showed that patients with PD have deficits in visual search of stationary targets against a stationary background (Archibald, Hutton, Clarke, Mosimann, & Burn, 2013; Cormack, Gray, Ballard, & Tovée, 2004; Lubow, Dressler, & Kaplan, 1999; Mannan, Hodgson, Husain, & Kennard, 2008). Impairments in exploration strategy, longer search time to find the target, increased number of errors, and eye movement abnormalities may contribute to impaired visual search in PD (Archibald et al., 2013). Similarly, patients with PD have difficulties identifying moving targets against a stationary background compared with control participants (Weil et al., 2016). Mestre et al. (1990) also showed that patients with PD have greater difficulty in detecting a moving drifting vertical grating than a static one, which was not the case for the controls. This finding may be explained by a specific deficit of motion perception in PD (Mestre et al., 1990).

Driving is a complex activity that requires drivers to search for and recognize both stationary as well as moving targets against a moving, highly cluttered background. In an on-road study, participants with PD identified fewer stationary road signs and landmarks when compared with healthy controls while driving (Uc et al., 2006). These impairments on a landmark and

traffic sign identification task were associated with impairments in visual attention and visuoconstructional abilities. To our knowledge, no research has been done in real-world situations where patients with PD have to identify moving targets such as cars in traffic while driving.

Drivers with PD who are engaged in a visual search task while driving also commit more driving safety errors compared to controls. These impairments in driving performance may be explained by the additional cognitive workload of attending to the visual search task while maintaining control over the vehicle (Uc et al. 2006). Cognitive workload refers to the total amount of mental effort being used in cognitive tasks (Kahneman, 1973). Pupillary responses such as the index of cognitive activity (ICA) may be used to accurately estimate cognitive workload in several cognitive tasks (*i.e.* digit span tasks or saccadic tasks) in different populations (Kahneman, 1973; Klinger, Kumar, & Hanrahan, 2008; Marshall, 2007; Ranchet et al., 2017). Patients with PD show increased ICA values during simple saccadic tasks compared to older adults (Ranchet et al., 2017).

Few studies have examined cognitive workload, using ICA in a driving context (Vogels, Demberg, & Kray, 2018). In the study of Vogels et al. (2018), the main objective was to investigate whether ICA was a sensitive measure of processing load due to a dual task in healthy individuals. Participants were asked to perform different tasks varying in complexity on a driving simulator: a simple listening task in which participants listened to different sentences, and a simple driving task in which the driver had to control the lateral position of the steering bar such that it overlaps with the yellow reference bar that moved horizontally across a straight road. In addition, participants had to perform a secondary memory task with two levels of difficulty while performing the simple tasks (listening or driving tasks). Findings showed that larger ICA reflected more difficult linguistic processing. However, the authors did not show an increase in the ICA in dual task (the most difficult memory task

associated with the listening task or the driving task) as compared to a single task (the listening task or the driving task). In the present study, the ICA was investigated in patients with PD. It may be an important metric to capture the cognitive workload exerted during the visual search task while driving. On-road tests have the advantage of providing an ecologically valid assessment of visual search. However, the lack of control over ambient stimuli (road and weather conditions, other road users) may affect the reliability of the visual search task. Driving simulators offer the opportunity to project stationary and moving targets in standardized and safe conditions, with complete control over the level of clutter, road and weather conditions, lighting of the room, and illuminance of the screens.

The main objective of this study was to investigate visual search performances (accuracy and correct response times) of both stationary and moving targets in patients with PD while driving through simulator-generated traffic scenarios. A secondary objective was to examine the role of cognitive functions in performing the visual search task while driving. An ancillary aim was to explore the cognitive workload, using ICA, during the visual search task.

2. Methods

2.1 Participants

Twenty-two patients and 17 controls were recruited between March 25, 2015 to April 1, 2016 from the outpatient Movement Disorders Clinic at Augusta University, GA, USA. Among them, 19 patients with PD and 14 healthy controls were included (Table 1). Three patients were excluded from the analyses due to difficulties understanding the task (n = 2) or simulator adaptation syndrome (n = 1). Three controls were excluded from the analyses due to difficulties understanding the task (n = 1), simulator adaptation syndrome (n = 1), or refusing to complete the driving task (n = 1). All participants had a valid driver's license, reported at least 500 miles of driving in the year prior to testing and had no other visual, neurological

(other than PD for the PD group), internal or psychiatric conditions that may interfere with driving.

Presence of dementia by clinician impression (J.C.M.) and Montreal Cognitive Assessment (MOCA) scores ≤ 15, other parkinsonian syndromes, severe dyskinesia, deep brain stimulation, unpredictable motor fluctuations, or ocular diseases causing significant visual impairment (glaucoma, stroke, eye vascular disorders, macular degeneration, etc.) were exclusion criteria.

Table 1 showed that patients were significantly older than controls and performed worse on the MOCA, even after adjusting for age ($p = 0.007$). Binocular visual acuity (range: 0 – 1) was assessed by the vision screening apparatus from Keystone view (Visionary Software version 2.0.14). All participants had normal-to-corrected vision. Driving experience of patients significantly differed from those of controls. When age was included as covariate in the analysis, no significant difference between groups in driving experience was found ($p = 0.76$). L-Dopa equivalent dosages (LED) (Deuschl et al., 2006) and motor scores on Unified Parkinson's Disease Rating Scale (UPDRS motor) were recorded. All but one patient were medicated. All patients were tested in the "on" medication state. The study was approved by the Augusta University institutional review board. Informed written consent was obtained from all participants.

Table 1. Demographic and clinical characteristics for all participants

Variable	PD patients N = 19	Controls N = 14	Test P-value
Age, years	68 ± 8	60 ± 11	t, **0.01**
Sex (male), n %	15 (80)	7 (50)	Fisher, 0.14

Education, years	17 (16 – 18)	14 (13 – 19)	W, 0.28	92
MOCA score, (0 – 30)	26 (20 – 28)	29 (27 – 30)	W, 0.003[a]	93
Visual acuity, (0-1)	0.8 (0.5 – 0.8)	0.8 (0.8 – 1)	W, 0.07	94
Driving experience	52 ± 8	42 ± 12	t, **0.01**[b]	95
Disease duration, years	5 (2 – 7)	NA		96
LED, mg/day	300 (200 – 855)	NA		97
Hoehn and Yahr stage (on)	2 (2 – 3)	NA		98
UPDRS motor (on)	31 (19.5 – 38.5)	NA		99
				100

101 LED = L-Dopa Equivalent Dosage; MOCA = Montreal Cognitive Assessment; NA = not
102 applicable; UPDRS = Unified Parkinson Disease Rating Scale; t = independent student t test;
103 W = Wilcoxon rank sum test

104 [a] Significant differences between the two groups after adjusting for age differences (p = 0.007)
105 [b] No significant differences between the two group after adjusting for age differences (p =
106 0.76)

107

108 2.2 Cognitive tests

109 Participants completed a series of tests assessing different cognitive functions. The MOCA
110 test is a brief screening tool for global cognition. It assessed different cognitive domains of
111 language, orientation, attention, memory recall, and visuospatial/executive functions (Hoops
112 et al., 2009). This test was scored on an ordinal scale ranging from 0 to 30. The Stroop color
113 and word test was administered to evaluate speed of processing and inhibition. The

participants were required to read 3 different tables as fast as possible. In the color naming condition, participants were required to name different color patches. In the word condition, participants were required to read names of colors. In the color-word condition, color-words are printed in an inconsistent color ink. Participants were required to name the color of the ink instead of reading the word. For each condition, the score in a time limit of 45 seconds was the main outcome. The Useful Field of View (UFOV) consisted of three subtests that evaluate speed of processing (SOP), divided attention (DA), and selective attention (SA) (Ball, Roenker, & Bruni, 1990). In the subtest 1 (SOP), participants were asked to identify a single object (car or truck) presented in the center of the screen. In the subtest 2 (DA), participants were asked to identify the object in the center of the screen and to simultaneously localize a peripheral target. Subtest 3 (SA)is similar to subtest 2, except that the peripheral target now appears among distractors. Scores in milliseconds were the mean exposure durations required to achieve 75% of correct responses. The Rey Osterrieth Complex Figure (ROCF) – copy test measured visuospatial and visuoconstructive abilities (Rey, 1941). During the ROCF, participants were asked to reproduce a complex figure on a blank sheet of paper. A score ranging from 0 to 36 was recorded. The Dot cancellation test assessed visual scanning and sustained attention (Lincoln & Radford, 2008). In this test, participants were instructed to read each line and mark all groups of four dots, while ignoring the groups of three dots and five dots. Total time and number of errors were recorded. The Trail Making Test (TMT) assessed psychomotor speed (part A) and executive functions (part B) (Reitan, 1958). During the TMT-part A, participants were asked to connect 25 circles with numbers in ascending order as fast as possible (e.g., 1, 2, 3 etc…). During the TMT-part B, participants were asked to alternate between numbers and letters as fast as possible. Time to completion was recorded for part A and part B of TMT.

2.3 Visual search in a driving simulator

The experiment was conducted using a desktop simulator with automatic transmission. The simulator has a three-screen front view with a horizontal field of 100 degrees and a vertical visual field of 20 degrees. The participant's eyes were at 42 inches from the center of the middle screen. Before performing the driving test, participants familiarized themselves with the simulator by driving a practice scenario for 10 minutes.

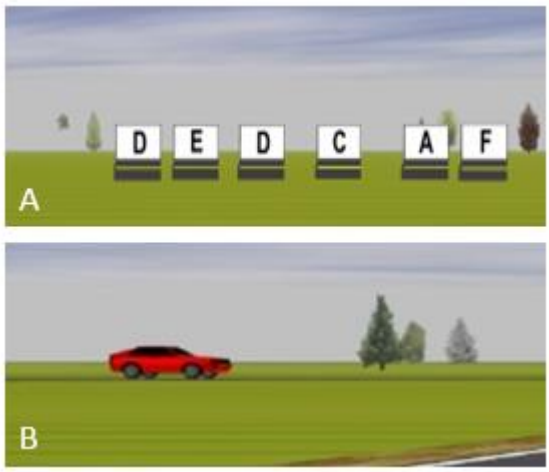
Visual search task

Participants were instructed to follow a lead car that was driving at 45 mph on average (Figure 1).

Figure 1. A: Screenshot of driving scene with a series of billboards on the right side of the road B: Screenshot of driving scene with a red car coming from the left side of the road

During driving, they had to search and identify both stationary and moving targets among other distractors by pressing either the right button of the steering wheel when the target was present or the left button when the target was absent. The stationary target was a billboard with the letter 'A' that was located among a series of five distractor billboards (Figure 2A). The billboards were located at 4 different degrees of eccentricity (left or right): 6.1°, 15.2°, 33.9°, 42.5°. The angles were calculated from the line between the eyes and the center of the

156 screen (42 inches) and the line between the eyes and the midpoint of the billboard. The
157 moving target was a red car among a series of five distractor cars that would pass the driver
158 from the left, right, front or behind (Figure 2B).



159

160 Figure 2 A: Enlarged picture of the billboard with the letter A (stationary target) among other
161 billboards B: Enlarged picture of the red car (moving target)

162 In total, there were 32 events along the road. In half of the events, the target (stationary or
163 moving) was present. Along the drive, wind gusts appeared randomly to keep participants
164 attentive to the road. Speed warnings were also played when participants were above or below
165 the speed limit (± 5 mph). The billboards appeared at 950 feet from the driver. It took 15
166 seconds for the driver to pass the billboard with a speed of 45 mph. Similarly, the red car
167 coming from left or right took 15 seconds to reach the intersection. The duration of the task
168 was 15 minutes.

169 Accuracy (in %), correct response times, number of correct responses, errors, and misses were
170 calculated. Errors included the number of "no detections" and the number of "false alarms".
171 No detections referred to the number of trials where the target was present and the participant
172 pressed the wrong (left) button. False alarms were defined as the number of trials where the
173 target was absent and the participant pressed the wrong (right) button. Misses referred to the

number of trials where they did not press any buttons. These measures were also calculated separately for the trials with stationary targets (billboards) and the trials with moving targets (red cars). Standard deviation of lateral position (SDLP) was recorded at 60 Hz.

2.4 Measures of ICA

The ICA was recorded during the visual search task by two synchronized, remote eye trackers (FX3, SeeingMachines Inc, Canberra, Australia) at 60 Hz. ICA detects small but reliable increases in pupil size while adjusting for individual differences in pupil size, lighting, and accommodation (Marshall, 2007). The ICA values ranged between 0 and 1, and were computed for left and right eyes (Marshall, 2007). Due to a relatively low number of errors in both groups, average cognitive workload was recorded only for the trials with stationary or moving targets where participants answered correctly.

2.5 Statistical analysis

Kolmogorov-Smirnov tests were used to determine the normality of variables. Between-group differences were examined using Fisher's Exact tests, independent student t tests or Wilcoxon rank-sum tests, as appropriate. Within-group differences were examined using paired t-tests or Wilcoxon signed-rank tests. Since age differed significantly between groups, univariate analyses of variance (ANOVA) or generalized linear models with age as covariate and group as between-group factor were performed. Spearman rank correlations (ρ) were analyzed to investigate associations between scores on cognitive tests and accuracy on the visual search task or SDLP within the PD and control groups. Correlations (ρ) were considered weak below 0.10, moderate between 0.10 and 0.49 and strong between 0.50 and 1.00 (Cohen, 1992). Chi-square analysis or Fisher's test were performed to determine the proportion of individuals in

each group who made one or more errors for each level of eccentricity. P values < 0.05 were considered significant. All statistical analyses were conducted using SPSS, version 24.0.

3. Results

3.1 Visual search performance

Patients were less accurate in the visual search task compared with controls (Table 2). The differences between groups were mainly driven by the poorer performance of the patients with PD in the stationary visual search task.

Table 2. Performance in the visual search task

Variable	PD patients N = 19	Controls N = 14	Statistic test, P value adjusted for age
Overall measures			
Accuracy[a], %	87 (80 – 96)	98 (96 – 100)	X^2, **0.002**
Correct response times, s	14 ± 2	14 ± 1	F, 0.48
Correct responses, n	23 ± 5	27 ± 2	F, 0.18
Misses, n	6 ± 5	5 ± 2	F, 0.84
Errors, n	3 (1 – 5)	0.5 (0 – 1)	X^2, **0.001**
No detections[b], n	1 (1 – 2)	0 (0 – 0)	X^2, **0.01**

False alarms[c], n	1 (0 - 3)	0 (0 - 1)	X^2, **0.03**
Stationary targets			
Accuracy[a], %	80 (64 – 90)	100 (92 – 100)	X^2, < **0.001**
Correct response times, s	13 (12 – 14)	13 (13 – 14)	X^2, 0.21
Correct responses, n	9 ± 3	12 ± 2	**F, 0.05**
Misses, n	4 (2 – 6)	4 (3 – 5)	X^2, 0.66
Errors, n	2 (1 – 4)	0 (0 – 1)	X^2, < **0.001**
No detections, n	1 (0 – 2)	0 (0 – 0)	X^2, **0.001**
False alarms, n	1 (0 – 2)	0 (0 – 1)	X^2, **0.047**
Moving targets			
Accuracy[a], %	100 (88 – 100)	100 (100 – 100)	X^2, 0.24
Correct response times, s	15 ± 2	14 ± 2	X^2, 0.57
Correct responses, n	15 (10 – 16)	15 (14 – 16)	X^2, 0.33
Misses, n	1 (0 – 2)	0 (0 – 1)	X^2, 0.45
Errors, n	0 (0 – 1)	0 (0 – 0)	X^2, 0.29
No detections, n	0 (0 – 0)	0 (0 – 0)	X^2, 0.59
False alarms, n	0 (0 –1)	0 (0 – 0)	X^2, 0.12
Driving measures			
SDLP (feet)	1.5 ± 0.3	1 ± 0.3	F, **0.049**

Values are expressed in median (Q1 – Q3) or mean ± SD

F, ANOVA; X^2, Chi^2; s, seconds; SDLP, Standard Deviation of Lateral Position

[a]Accuracy = $(n_{hit\ present} + n_{hit\ absent}) / (n_{hit\ present} + n_{hit\ absent} + n_{no\ detections} + n_{false\ alarms})$

[b]Number of trials with a target present where the participant pressed the wrong (left) button

[c]Number of trials with a target absent where the participant pressed the wrong (right) button

Stationary targets

The number of errors, including the number of no detections and false alarms was significantly higher in patients than in controls (Table 2). These errors particularly emerged at greater angles of eccentricity. At 33.9 degrees and 42.5 degrees, a greater proportion of patients than controls made at least one error (Table 3).

Table 3. Proportion of individuals in each group who made at least one error at different levels of eccentricity

		Proportion of individuals who made at least one error at different degrees of eccentricity							
		6.1°		15.2°		33.9°		42.5°	
		no	yes	no	yes	no	yes	no	yes
Controls	n	13	1	11	3	11	3	11	3
	%	93	7	79	21	79	21	79	21
Patients	n	14	4	8	10	7	11	6	12
	%	78	22	44	56	39	61	33	67
P value		0.36		0.08		**0.04**		**0.02**	

222 Moving targets

223 No significant differences between groups were found in any measures of visual search of
224 moving targets.

225 Driving performance

226 SDLP was different between patients and controls.

227 3.3 Cognitive functions associated with visual search performance

228 After adjusting for age, the PD group performed worse than the controls group on the Stroop
229 test (color naming and interference conditions), the ROCF test, and the TMT test (part A and
230 B) (see table 4).

231 Table 4. Comparison of cognitive performances between the two groups

	PD patients N = 19	Controls N = 14	Test Statistic, P value adjusted for age
Stroop color, score	53.13 ± 15.39	74.29 ± 20.47	F, **0.03**
Stroop word, score	81.63 ± 27.46	95.29 ± 14.13	F, 0.39
Stroop C/W, score	28.44 ± 13.07	40.71 ± 6.01	F, **0.03**
UFOV SOP, ms	17.00 (16.70 – 63.50)	16.70 (16.70 – 16.70)	X^2, 0.13
UFOV DA, ms	166.70 (47.00 – 500.00)	35.20 (16.70 – 70.10)	X^2 , 0.06
UFOV SA, ms	321.75 (169.00 – 500.00)	175.10 (96.80 – 220.00)	F , 0.19
ROCF, score	32.00 (25.00 – 35.50)	36.00 (34.00 – 36.00)	X^2 , **0.02**
Dot cancellation, s	608.58 ± 210.62	420.90 ± 207.18	F, 0.14
Dot cancellation, errors	5.00 (2.00 – 14.00)	4.00 (2.00 – 6.00)	X^2, 0.48
TMT A, s	46.87 (32.40 – 65.90)	26.73 (21.00 – 33.76)	X^2, **0.03**

TMT B, s	128.24 (79.70 – 177.15)	64.88 (52.91 – 73.18)	X^2, **0.03**
TMT (B-A), s	81.00 (45.19 – 135.43)	43.51 (32.00 – 104.80)	X^2, 0.41

Values are expressed in mean ± SD or median (Q1 – Q3)

Abbreviations: DA, divided attention; C/W, color-word; ms, milliseconds; ROCF, Rey-Osterrieth Complex Figure; s, seconds; SA, selective attention; SOP, speed of processing; TMT, Trail Making Test; UFOV, Useful Field Of View

Within the group of patients, TMT B completion time, TMT (B – A) cost, dot cancellation test completion time, SOP and DA of the UFOV test correlated significantly and strongly with visual search accuracy (Table 5). Score on MOCA and TMT A completion time correlated significantly and moderately with visual search accuracy.

By contrast, only the score on the MOCA test correlated significantly and strongly with visual search accuracy ($\rho = 0.63$, $p = 0.02$) in the control group.

Within the group of patients, TMT B completion time, TMT B – A cost, dot cancellation test completion time, and DA and SA of the UFOV test correlated significantly and strongly with SDLP. TMT A completion time and errors on the dot cancellation test correlated significantly and moderately with SDLP (Table 5).

Within the group of controls, only TMT B completion time ($\rho = 0.61$, $p = 0.02$) and errors on the dot cancellation ($\rho = 0.74$, $p = 0.003$) correlated significantly and strongly with SDLP.

Significant and strong Spearman correlation was also found between SDLP and visual search accuracy only in the group of patients ($\rho = -0.63$, $p = 0.004$).

251 Table 5. Significant correlations between accuracy, SDLP and cognitive measures within the

252 group of patients (n = 19)

Simulator measures	Cognitive measures	Spearman correlation coefficient
Visual search accuracy	MOCA score, / 30	0.47*
	TMT A, s	-0.46*
	TMT B, s	-0.61**
	TMT (B – A), s	-0.64**
	Dot cancellation test, s	-0.66*
	UFOV SOP, ms	-0.51*
	UFOV DA, ms	-0.56*
SDLP	TMT A, s	0.49*
	TMT B,s	0.62**
	TMT (B – A), s	0.60*
	Dot cancellation test, s	0.68*
	Dot cancellation test, errors	0.46*
	UFOV DA, ms	0.68**
	UFOV SA, ms	0.50*

253 *P < 0.05 **P < 0.01

Abbreviations: DA, divided attention; ms, milliseconds; s, seconds SA, selective attention; SOP, speed of processing; TMT, Trail Making Test; UFOV, Useful Field Of View

3.2 Values of cognitive workload, using ICA

No significant differences in average cognitive workload were found between the two groups for the trials where participants correctly identified either the stationary or moving visual search targets, after adjusting for age (table 6).

Table 6. Values of cognitive workload for the trials where the participant performed the visual search task correctly

Cognitive workload	PD Patients	Controls	P value adjusted for age[a]
Stationary targets			
Workload, left eye	0.33 ± 0.12	0.33 ± 0.13	F, 0.80
Workload, right eye	0.32 ± 0.15	0.34 ± 0.12	F, 0.89
Moving targets			
Workload, left eye	0.36 ± 0.09	0.35 ± 0.13	F, 0.92
Workload, right eye	0.36 ± 0.08	0.31 ± 0.15	F, 0.51

[a] $p > 0.05$ for all measures even after adjusting for age and accuracy

4. Discussion

This study aimed at investigating visual search performance using a driving simulator in drivers with PD. Visual search plays a major role while driving a car since individuals need to constantly search the driving scene ahead for relevant information that may cause a change in their current driving. During driving, the visual search task consisted of identifying stationary

and moving targets. Neuropsychological tests were also administered to better understand the role of cognitive functions underlying efficient visual search performance while driving in PD. To explore the degree of cognitive workload required to perform correctly the visual search task, we used the index of cognitive activity (ICA), extracted from pupillary responses.

Drivers with PD performed worse than controls on a visual search task while driving, particularly when patients were searching for the stationary targets (billboards) in the outer periphery. This result on a driving simulator is in accordance with findings from an on-road study (Uc et al., 2006), which showed that drivers with PD identified fewer landmarks and traffic signs than controls. Our findings suggest that some patients have restricted functional visual field that may impact their visual search task and their driving behavior. This result is in accordance with correlation analyses between UFOV performances and visual search accuracy or SDLP, and consistent with the literature (Classen et al., 2009; Uc et al., 2006). It is also possible that muscle stiffness (rigidity) and slow movements (bradykinesia) in the neck and trunk impaired their ability to scan in the periphery.

No significant differences between groups in visual search accuracy were observed for the trials where the driver had to identify moving targets, possibly due to the fact that participants waited the maximum allotted time (15 seconds) to respond. By that time, the moving target (the red car) had reached the intersection and was located in the participants' central visual field.

In contrast to controls, our findings suggest that patients need a wide range of specific cognitive functions to correctly identify the visual search targets while driving. In the group of patients, measures of executive functions, visual scanning, speed of processing and divided attention correlated with accuracy on the visual search task. In the control group, a measure of global cognitive function (MOCA test) correlated with accuracy. Results are also consistent

with those from a previous study (Uc et al., 2006). Indeed, tests assessing visual speed of processing and attention (Useful Field of View) and visuospatial abilities (Rey Osterrieth Complex Figure) were found to be the most important predictors of landmark and traffic sign identification (Uc et al., 2006). Similar correlations were found between cognitive measures and SDLP in patients with PD suggesting that driving performance was associated with several cognitive abilities. Furthermore, strong negative correlations were found in the PD group between driving performance, indexed by SDLP, and visual search accuracy. This strong negative correlation suggests that unlike controls, participants with PD who scored poorly on the visual search task, also showed difficulties with maintaining lane position. The present study shows that a visual search task during driving on a simulator may reflect cognitive deficits in patients with PD that may affect their driving behavior.

During the visual search task, cognitive workload, measured by change in pupil size and transformed to the ICA, was examined for the trials where participants correctly performed the task. Patients did not show greater cognitive workload than controls to correctly identify either the stationary or moving visual search targets. Our results are consistent with findings from Vogels et al. (2018) where no increase in ICA was found when participants performed a dual task condition. Our findings may suggest that patients who performed the task correctly did not work harder than controls to perform the visual search task. Further studies should be conducted to confirm the usefulness of pupillometry as a measure of cognitive workload in patients with PD, particularly for those who have subtle cognitive deficits.

4.4 Limitations

The sample size was small which limits the generalizability of the results. Caution with comparing the results of the stationary visual search tasks with the moving visual search tasks

is warranted as the characteristics (e.g shape, color) of the stationary and moving targets were not the same.

4.5 Conclusions and perspectives

Drivers with PD performed worse than controls on a visual search task while driving, particularly for the stationary targets in the outer periphery. Findings on neuropsychological tests highlight the major role of specific cognitive functions in drivers with PD in both visual search and driving performance. This driving simulator study expands on the findings from an on-road study (Uc et al., 2006), and suggests that it is possible to use the driving simulator to assess both visual search deficits and driving behavior in patients with PD. This visual search task in the driving simulator may help researchers and clinicians to better understand the cognitive and visual deficits of patients with PD that may affect their driving performance. Future studies should be conducted in a larger sample size to determine whether a visual search task on a driving simulator may predict on-road driving performances.

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