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Parkinson's disease affects gaze behavior and performance of drivers

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Parkinson's disease affects gaze behavior and performance of drivers

The aim of this study was to investigate the effects of PD and aging on gaze behavior and performance of drivers in a simulated task. Ten drivers with PD, ten neurologically healthy older drivers, and ten neurologically healthy younger adult drivers were asked to drive in a car simulator for three minutes, maintaining car speed between 100 and 120 km/h and avoiding collisions. Driver's eye movements were recorded. Drivers with PD had more collisions and spent less time driving within the speed zone than the younger-drivers. Drivers with PD performed an increased number of fixations towards task-irrelevant areas of the visual scene and higher visual entropy, indicating a more random gaze behavior. Older drivers restricted their visual search to the lane area in order to detect threat-related stimuli. PD led to drops in performance of drivers in the car simulator.

Keywords: Parkinson's disease; aging; visual entropy; eye movements, driving simulator.

Practitioner Summary: Parkinson's disease (PD) and aging process caused a drop in driving performance. Drivers with PD made fewer fixations on task-relevant information and showed higher visual entropy than young adults. Older drivers restricted their visual search to the lane than other areas of interest.

Introduction

According to the World Health Organization about 1.25 million people die by traffic accident and about 20 to 50 million victims become disabled by non-fatal crashes each year worldwide (World Health Organization 2016). Among the leading causes of death in Brazil, traffic crashes kill more than 40 thousand people per year (Instituto de Pesquisa Econômica Aplicada 2015; World Health Organization 2015). As populations around the world are rapidly aging, the number of older drivers and/or with disorders associated with the aging process, such as Parkinson's disease (PD) and Alzheimer's disease is likely to increase. Although driving impairments occur in PD patients, the higher involvement in motor vehicle accidents compared to their age-matched pairs is still not well established (Ranchet, Devos & Uc, 2020; Thompson et al., 2018; Ueno et al., 2018; Zesiewicz et al. 2002).

PD is characterized by motor symptoms, and additional symptoms including losses in cognitive functions (e.g., loss of processing multiple resources in dual-tasks) and impairments in visual skills (e.g., lower contrast sensitivity, deficits in the visual processing, more erratic eye movements during visual target detection in the peripheral area under different eccentricities and reduced useful field of view - UFOV), which can affect driving performance (Crizzle et al. 2012; E. Uc et al. 2006; E. Y. Uc et al. 2007). Particularly, drivers with PD showed less visual search accuracy in identifying targets while driving in a simulator compared to their pairs (Ranchet et al., 2020) and a reduced saccades amplitude during visual scanning tasks due to the Basal Ganglia dysfunction (Matsumoto et al., 2012). Regarding driving performance, PD patients have showed significantly worse driving performance (i.e., driving in a slower velocity, more often lane deviation and unsafe driving behavior such as stopping in inappropriate circumstances) compared to neurologically healthy individuals (E. Uc et al. 2006; E. Y. Uc et al. 2007). Decreased safety in PD drivers can also occur due to cognitive and perceptual skills deterioration due to the disease progresses. During a driving simulation task under low-contrast visibility conditions, drivers with PD presented poorer vehicle control and a higher risk for accidents (E. Uc et al. 2009). In addition, PD-drivers identified significantly less landmarks and traffic signs, and they committed more driving errors than their age-matched drivers (E. Uc et al. 2006). Overall, driving is intrinsically linked to visual perception and the investigation of the adverse effects of PD on visual and motor skills is essential. In other locomotion tasks, such as walking around an obstacle and/or walking to step onto targets on the floor, people with PD have shown a greater engagement to the visual information than their age-matched pairs (Vitório et al. 2016; Simieli et al. 2017). While walking along a pathway and aiming to step onto targets, PD patients showed more often stepping errors (i.e., erroneous foot placement onto targets) and directed their gaze earlier towards the first target than the control group (Vitório et al. 2016). Additionally, people with PD made more stepping adjustments during the approach walking and at the moment of obstacle circumvention – with longer gaze fixations on the pathway and obstacle than in other areas of the visual scene – compared to the control group without PD (Simieli et al. 2017). In both studies, the authors suggested that PD patients were more dependent on visual information to make on-line corrections and stepping adjustments, which seems to be due to deficits on working memory and/or executive functions provoked by the disease (Vitório et al. 2016; Simieli et al. 2017). In driving, these cognitive deficits might be reflected in longer gaze fixations to acquire the relevant visual information for controlling the vehicle compared to drivers without PD.

Furthermore, age-related changes on perceptual and motor behavior could contribute *per se* to decreased driving performance. Older drivers – neurologically healthy individuals – have shown a reduced UFOV, which is associated with a higher likelihood to incur in crash accidents (Owsley et al. 1998), slower reaction time in dual-task driving (Leversen, Hopkins, and Sigmundsson 2013), and more erratic saccadic eye movements during visual target detection in peripheral area under different eccentricities (Beurskens and Bock 2012) compared to young adult drivers. Elderly drivers can be characterized as suffering from a loss of multiple resources processing in more complex tasks and, consequently, this limitation may reflect on gaze behavior (Schieber and Gilland 2008). In a dual-task driving experiment, as cognitive demand increased, older drivers showed lower visual entropy compared to the low-demand dual-task and the single-task conditions; while younger drivers showed non-significant changes on eye movements' pattern with manipulation (Schieber and Gilland 2008). The visual entropy has been used as a new metric in the assessment of the gaze behavior (Gotardi et al. 2018; Holmqvist et al. 2011; Shic et al. 2008). Based on Information

Theory (Shannon 1948), where entropy is related to system complexity, lower entropy values correspond to a more ordered pattern of eye movements while higher visual entropy would indicate a more random visual scanning (Schieber and Gilland 2008). It has been argued that high values of entropy may indicate an inclination for exploration while lower visual entropy would refer to a more restricted visual exploration (Shic et al. 2008). These changes in gaze behavior over the years can affect elderly drivers in controlling the vehicle and detecting task-relevant information. Thus, it is expected that the aging process would have an adverse impact on gaze behavior (Beurskens and Bock 2012; Schieber and Gilland 2008; Owsley et al. 1998) as well as a decline in driving performance (Leversen, Hopkins, and Sigmundsson 2013; Owsley et al. 1998), regardless of the presence of neurodegenerative diseases such as PD. Therefore, the distinction between the effects of Parkinson's disease and those from aging on gaze behavior and motor performance of drivers becomes necessary.

The aim of the study was to identify the effects of PD and aging on gaze behavior and performance of drivers in a simulated task. It was expected that drivers with PD would exhibit a poorer performance in the driving simulator, showing a greater difficulty in control the speed vehicle and also a higher crashes involvement (Crizzle et al. 2012), compared to the older and younger drivers; whereas older people would drive more in erroneous speed compared to young adults, corroborating previous findings (Leversen, Hopkins, and Sigmundsson 2013; Owsley et al. 1998). In terms of gaze behavior, it was supposed that drivers with PD would show a greater number of gaze fixations and longer fixation time compared to older and younger drivers. As Uc and colleagues (E. Uc et al. 2006) found that drivers with PD identify less task-relevant information than neurologically healthy drives; it was expected that PD-drivers would perform fewer fixations towards relevant areas of the visual scene (i.e., lane, rearview mirror, and speedometer) than older and younger drivers. In addition, it was hypothesized that older drivers neurologically healthy would exhibit lower visual entropy compared to the younger drivers, corroborating previous study (Schieber and Gilland 2008), due to their more restricted multiple resources processing provoked by aging process. Regarding the PD-drivers group, it was also expected a more ordered pattern of eye movements (i.e., low values of visual entropy) than young adults, as a result of the visual/cognitive deficits provoked by the disease, indicating a dysfunctional more restricted visual scanning behavior.

Method

Participants

Thirty active and licensed drivers voluntarily participated in this study. Ten drivers with PD (PD-drivers), ten neurologically healthy older adult drivers (older-drivers), and ten neurologically healthy younger adult drivers (younger-drivers) participated in a driving simulator task (Table 1). To avoid the effects of driving experience, only experienced drivers who reported more than 30,000 kilometers driven were selected in all groups. See details of drivers' experience quantification in Gotardi and colleagues (Gotardi et al. 2019). To control the participants' visual acuity, the Snellen test was conducted and individuals who obtained scores between 20/20 and 20/30 were selected. Participants signed out the informed consent prior to any intervention approved by Ethical Local Committee (#45169015.2.0000.5505).

[Table 1 near here]

Driving simulator

The training car simulator City Car Driving (Forward Development, Home Edition, version 1.5) was configured to simulate a Brazilian driving scenario. The software was run on a Dell computer (Windows 10) in which was attached to a cockpit (XT Premium V2 Racing Extreme) with a Gamer Logitech G27 driving controllers (steering wheel, turning signals, brake, accelerator and clutch pedals, a gearbox of five speeds and the reverse) and a TV screen (Samsung 46") placed at 100 cm away from participants' seat. The driving simulator was configured in Free driving mode: *i)* area: multi-lane highway; *ii)* transport: left-handed car with manual gearbox, power 1.2; *iii)* traffic: 20% of vehicle traffic density, 0% of passenger traffic density, emergency situations to not occur; *iv)* weather/visibility: summer, clear, daytime. Participants' perspective was configured as the driver-view from inside the vehicle, including the rear-view mirrors (left, right, and central) and a digital speedometer (figure 1a). Accelerator and brake pedals were set up in 50% of pressing speed and steering wheel sensitivity was reduced to zero in order to approximate to the real-life experience. Potential distractors such as show violation messages, controls indication and/or GPS instructions were disabled. The route consisted in driving straight ahead in a multi-lane highway. No unexpected route deviation was programmed in the software. If any participant deviated from the original route, the task was interrupted and, after clarification of the task instructions, it was resumed. Participants were free to adopt overtaking strategy in order to avoid collisions and/or to maintain the vehicle speed. Traffic behavior was typical to metropolitan highways with vehicles in the left lanes driving in higher speed than those in the right ones. Dangerous traffic events were not configured. Collisions would occur by unsuccessful overtaking maneuver (including not using the turning signals) and/or driving too fast or too slow in the wrong lane. When collisions occurred, test timer was stopped and the experimenter set the simulator to start at the same location where the collision occurred. Once the participant was ready to perform again, timer was released. In total, participants drove 3 min of consecutively driving.

Eye-tracking

Eye movements were recorded using a Head-Mounted Eye Tracker (model H6, Applied Science Laboratory), at a sampling rate of 60 Hz. This video-based analysis system of eye movements contains two micro-cameras, one that films the eye and another one the scene, attached to a headgear that was anatomically adjusted to the participant's head. In the eye video, pupil and corneal reflection centroids were identified and the vector between both is used to determine horizontal and vertical coordinates of eye position in the scene video (figure 1b).

[Figure 1 near here]

Procedure

Drivers with PD were tested during their ON-state of medication of the PD (i.e., approximately one hour after taking the dose of LEVODOPA). Prior to the start of the test, participants were asked to take a seat in the cockpit and had the eye tracker's headgear adjusted on their head. A nine-point calibration was conducted to adjust the eye tracker accuracy. Participants were asked to drive during three minutes on the highway, and maintaining car speed between 100 and 120 km/h and avoiding collisions. Participants had three minutes to familiarize themselves with the simulator and equipment before the experimental starting. Trial start was timed when drivers reached 100 km/h for the first time.

Data analysis

In offline frame-by-frame video analysis, driving performance was assessed by both the percentage of time driving within the speed range (%VEL) and the number of collisions (COL) made throughout the trial. The %VEL was considered by the period of time (s) that car's speed remained within the speed range (i.e., 100 – 120 km/h) divided by the total trial's time and multiplied by 100. The number of collisions per trial was counted during the time valid within the trial determining the COL for each participant. The coefficients of variation of %VEL (%VEL-cv) and COL (COL-cv) were computed to provide the variability of the car speed and the number of collisions throughout trial, respectively. It was calculated using the standard deviation of the data divided by the average of the data and multiplied by 100, in order to normalize the variation of the signal in relation of its magnitude.

The ASL Results Plus software (version 1.8.2.18, ASL) was used for eye movements analysis. In order to assess how often visual inspections were made and for how long these inspections last, both the total number of fixations (nFIX) and total fixations duration (dFIX) were calculated for each participant. Fixation detection criteria included a minimum duration of 100 milliseconds and the spatial limit of 1 degree of visual angle. The coefficients of variation of nFIX (nFIX-cv) and dFIX (dFIX-cv) were computed to calculate the variability of the nFIX and dFIX, respectively. Additionally, analyses by Areas of Interest (AOIs), two-dimensional (2-D) regions defined on the viewing plane were made. Four AOIs were considered: i) lane, which provides the essential visual information to steering control; ii) speedometer, task-relevant information; iii) rearview mirrors, task-relevant information for deciding overtakes; and iv) outside, any part of the visual scene not considered an AOI. The total number of fixations and total fixations duration were calculated per AOI.

Entropy was applied to identify whether drivers' visual scanning behaves randomly or, alternatively, more predictably as a result of PD and/or aging. The entropy was quantified based on Information Theory (Shannon 1948) through to the conditional transition-probability matrices between AOIs. When entropy is high, drivers fixated their gaze on all AOIs an equal number of times and will make gaze transitions between all possible combinations of AOIs with a near equal frequency. Alternatively, lower entropy indicates that gaze fixations pattern become more ordered, less complex. The entropy was calculated following the Equation 1:

$$H(R) = -\sum_{r_i} p\,(r_i) log_2\, p(r_i), r_i > 0 \qquad (1)$$

where R is a normalized transition matrix and r_i are cell values of that matrix with probabilities p(r_i).

Finally, the relative entropy was measured by dividing the observed entropy by the maximum value of entropy. The relative entropy allows the comparison of results across groups and other studies (Schieber and Gilland 2008).

Statistical analysis

The one-way ANOVAs with a between-subject group factor (younger-drivers, older-drivers, PD-drivers) were performed on the following dependent variables: *i)* Driving performance – %VEL, %VEL-cv, COL, COL-cv; *ii)* Overall fixations pattern – nFIX, nFIX-cv, dFIX, dFIX-cv and relative entropy; and *iii)* visual scanning across AOIs – nFIX-aoi and dFIX-aoi. Statistical analyses were run using SPSS Statistics (17.0.1). Tukey Honestly Significant Difference tests, Greenhouse-Geisser degrees of freedom adjustments, and Bonferroni multiple-comparison probability adjustments (Threshold = .0166) were conducted in statistical analyses as necessary. The value alpha was .05. Effect sizes were calculated using Eta Squared with 0.02 or less, approximately 0.13, and 0.26 or more, representing small, medium, and large effect sizes, respectively (Cohen 1988).

Results

Driving performance

For the %VEL and COL (Figure 1), the analysis revealed a main effect for group, $F(2,27) = 49.716$, $p < .001$, $\eta_p^2 = .786$ and $F(2,27) = 7.353$, $p = .003$, $\eta_p^2 = .353$, respectively. Post-hoc tests indicated that both groups of elderly drivers, with or without PD, spent less time driving within the required speed range (100-120 km/h) throughout total trial time, PD-drivers: 6.76 ± 9.56 % of total trial time and older-drivers: 13.72 ± 20.52 % of total trial time compared to younger-drivers: 71.01 ± 13.45 % of total trial time. Particularly, PD-drivers spent 35.28 ± 22.53 % of total trial time driving within 01-60 km/h, 52.68 ± 22.19 % of total trial time driving within 61-99 km/h, and 0.09 ± 0.22 % of total trial time driving above 121 km/h. Older-drivers spent 27.57 ± 16.17 % of total trial time driving within 01-60 km/h, 52.55 ± 23.98 % of total trial time driving within 61-99 km/h and 0.34 ± 0.89 % of total trial time driving above 121 km/h. Finally, younger-drivers spent 0.10 ± 0.001 % of total trial time driving within 01-60 km/h, 1.52 ± 2.59 % of total trial time driving within 61-99 km/h, and 8.97 ± 0.10 % of total trial time driving faster than 121 km/h. Older- and PD-drivers spent most part of the total trial time driving slower than the required speed range. Furthermore, PD-drivers performed higher rate of collisions than younger-drivers. Yet, there were no differences between younger-drivers and older-drivers or older-drivers and PD-drivers. For both %VEL-cv and COL-cv there was no significant main effect for group, $F(2,27) = 3.060$, $p = .063$, $\eta_p^2 = .185$ and $F(2,27) = 1.592$, $p = .222$, $\eta_p^2 = .105$, respectively.

[Figure 2 near here]

Overall fixations pattern

For the nFIX and nFIX-cv (Figures 2A and 2B), the analyses revealed a main effect for group, $F(2,27) = 3.705$, $p = .038$, $\eta_p^2 = .215$ and $F(2,27) = 4.934$, $p = .022$, $\eta_p^2 = .246$, respectively. Post-hoc tests indicated that PD-drivers performed a greater nFIX than older-drivers, but showed no differences compared with younger-drivers or between older-drivers and younger-drivers. Furthermore, PD-drivers showed greater nFIX-cv compared to younger-drivers, but no differences in comparison to older-drivers. For the dFIX and dFIX-cv (figures 2C and 2D) the analyses revealed a main effect for group, $F(2,27) = 4.451$, $p = .021$, $\eta_p^2 = .248$ and $F(2,27) = 5.606$, $p = .009$, $\eta_p^2 = .293$, respectively. PD-drivers performed shorter dFIX than younger-drivers, but no differences between PD-drivers and older-drivers. Furthermore, PD-drivers showed higher dFIX-cv compared to older and younger-drivers.

For the relative visual entropy (Figure 3), the analysis revealed a main effect for group, $F(2,27) = 5.300$, $p = .011$, $\eta_p^2 = .282$. PD-drivers showed higher visual entropy compared to younger-drivers, but no differences to older-drivers neither between younger and older-drivers.

[Figure 3 near here]

[Figure 4 near here]

[Figure 5 near here]

Visual scanning across AOIs

A complete overview of means and SDs of the gaze behavior in each AOI is provided in Table 2. For the n-FIX on the AOI outside, the analysis revealed a main effect for group, $F(2,27) = 4.018$, $p = .030$, $\eta_p^2 = .229$. PD-drivers performed a greater n-FIX towards outside (irrelevant stimulus) than younger-drivers, but there were no differences in comparison to older-drivers. For the d-FIX on the outside, there was non-significant effect for group, $F(2,27) = 2.086$, $p = .144$, $\eta_p^2 = .134$. For the d-FIX on the lane, the analysis revealed a main effect for group, $F (2,27) = 4.063$, $p = .029$, $\eta_p^2 = .231$. Post-hoc tests indicated that PD-drivers spent less time fixating at the lane compared to older-drivers, while showed no differences to younger-drivers. For n-FIX towards lane, the analysis revealed no main effect for group, $F (2,27) = 3.327$, $p = .051$, $\eta_p^2 = .198$. For the n-FIX and d-FIX on the speedometer, the analyses revealed a main effect for group, $F (2,27) = 7.277$, $p = .003$, $\eta_p^2 = .350$ and $F (2,27) = 5.867$, $p = .008$, $\eta_p^2 = .303$, respectively. Younger-drivers spent more time looking, performing a greater n-FIX, towards the speedometer than older-drivers. There were no significant differences between PD-drivers to younger-drivers and older-drivers. For the n-FIX and d-FIX on the AOI rearview mirrors, the analyses revealed no main effect for group, $F(2,27) = 1.063$, $p = .359$, $\eta_p^2 = .073$ and $F(2,27) = .295$, $p = .747$, $\eta_p^2 = .021$, respectively.

[Table 2 near here]

Discussion

The aim of this study was to investigate the effects of PD and aging on gaze behavior and performance of drivers. The novelty of the manuscript is to contribute with evidences of how PD and aging differently affect the visual scanning pattern in driving. Adverse changes on gaze behavior may indicate an impaired acquisition of task-relevant information, which can be related to the poorer performance demonstrated by both drivers with PD and elderly drivers. Both PD-drivers and older-drivers distinguished from the performance of the younger-drivers; however, non-significant difference was found between their driving performance, in contrast to previous evidence (E. Uc et al. 2006; E. Y. Uc et al. 2007). The results of the present study revealed that PD-drivers were more involved in simulated car collisions and spent less time driving within the speed zone compared to the younger-drivers, confirming that PD disrupts driving performance (Crizzle et al. 2012; E. Uc et al. 2006; E. Y. Uc et al. 2007). Moreover, older-drivers also spent more time driving in erroneous speed than younger-drivers, corroborating with previous studies that have showed adverse effects of aging process on driving behavior (Leversen, Hopkins, and Sigmundsson 2013; Owsley et al. 1998). This result partially confirms study main hypothesis about driving performance. One possible explanation for understanding the similarity between PD-drivers and older-drivers is that the simulated driving environment was a challenging task for both groups. The challenging of the task can be increased due to cognitive/motor deficits provoked by both aging process (Leversen, Hopkins, and Sigmundsson 2013; Owsley et al. 1998) and PD (Crizzle et al. 2012; E. Uc et al. 2006; E. Y. Uc et al. 2007). These deficits affect the drivers' ability to control the vehicle and to detect task-relevant information in the environment, provoking a disrupted perceptual and motor performance. In addition, despite of several studies have used and indicated car driving simulators to scientific research (Zesiewicz et al. 2002; Gotardi et al. 2019; Winter, Leeuwen, and Happee 2012; Gotardi et al. 2018), due to the various advantages such as controllability, reproducibility and standardization of the experimental conditions, the time exposure and familiarity of the elderly population (PD and non-PD) to the virtual environment are more restricted compared to young adults (NPD 2015). In Brazil, 82% of those within the 13-59 age range self-reported as video game players on at least one gaming platform (NPD 2015). The unfamiliar environment may have demanded much more from both elderly groups (with or without PD) to perform in driving simulator. Although the simulated driving task in this study has lasted a relatively short period of time (i.e., three minutes) in comparison to what drivers usually do in daily real traffic experience; this driving task duration is aligned with previous studies that investigated the behavior of drivers in virtual environments (Gotardi et. al., 2018; 2019a; 2019b). All participants, including older- and PD-drivers, were experienced drivers and were able to show a stable driving performance in the simulated environment until the end of the familiarization session. The familiarization session also lasted 3-min of continuous simulated driving, which represents 100% of the total driving task duration. The duration of the familiarization session and the driving task was considered sufficient for investigating perceptual-motor behavior of drivers. Alternatively, a longer practice time for both groups of elderly drivers compared to the younger one would insert a potential bias of learning on the data.

The analyses of overall pattern of fixations found that PD-drivers performed a greater number of fixations compared to older-drivers and showed a larger variability in both number of fixations and total fixations duration than both older-drivers and younger-drivers, confirming our hypothesis related to gaze behavior. Interestingly PD-drivers and older-drivers adopted a different visual search strategy to perform the task. The AOIs analyses indicated that PD-drivers performed a greater number of fixations towards the outside area than younger-drivers, while older-drivers spent more time performing fixations to the lane than PD-drives. In the present study, three areas of the visual scene were defined as the main sources of task-relevant information to perform the driving task (i.e., lane, speedometer and rearview mirror). The outside area represented any part of the visual scene not considered as an area of interest. Confirming the hypothesis of the study, PD-drivers performed more gaze fixations towards task-irrelevant information (i.e., outside area) compared to younger-drivers, corroborating previous study (E. Uc et al. 2006). Although the PD-drivers of this study increased the overall number of fixations, their visual attention was shifted towards task-irrelevant information which indicates a reduction of the goal-directed control (Derakshan et al. 2009). On the other hand, the superior driving performance among younger-drivers was associated with increased monitoring of the speedometer. It seems that the attention of the younger-drivers was shifted toward task-relevant information, arguably in an attempt to consciously adhere to speed instructions. In contrast, although the older-drivers sought information in a relevant area of the visual scene, they were unable to use the information for maintaining the driving performance. It could be argued that older-drivers restricted their visual search to threat-related stimuli (i.e., other cars on the lane to avoid collisions) rather than keeping the vehicle speed. Since young adults present enough cognitive resources to process both tasks of maintaining the vehicle speed and avoiding collisions, the attentional shifting between the lane and speedometer becomes an efficient visual strategy. However, for older-drivers this dual-task impaired driving performance by the lower capacity of multiple resources processing as a result of the aging process (Schieber and Gilland 2008; Leversen, Hopkins, and Sigmundsson 2013).

In contrast to the study's hypothesis, PD-drivers showed higher visual entropy than younger-drivers. Higher entropy corresponds to an unpredictable and more random eye movements' pattern. It still controversial the interpretation of what visual entropy represents on gaze behavior (Gotardi et al. 2018; Holmqvist et al. 2011; Shic et al. 2008). It has been argued that a more random visual scanning implies into less acquisition of information as well as a higher effort spent (Holmqvist et al. 2011). On the other hand, higher visual entropy may indicate a preference for exploration while low values indicate lower tendency to explore hence fewer areas of interest are visited (Shic et al. 2008). It can be suggested that PD-drivers sought to explore more the environment in order to detect information and to avoid the performance disruption. However, as AOI analyses evidenced, they were unable to look at the task-relevant areas of the visual scene, indicating an inefficient visual scanning strategy. In studies with locomotion tasks such as walking around an obstacle or walking to step onto visual targets on the floor, people with PD have shown a greater engagement to the visual information than their age-matched pairs (Vitório et al. 2016; Simieli et al. 2017). It has been suggested that due to working memory and/or executive functions deficits provoked by the disease, people with PD increase the overall number of fixations to deal with the difficulty remembering of locations and longer period fixating as a result of slower processing capacity (Simieli et al. 2017). In addition, the results of the visual entropy in PD-drivers brought new insights to understand how the disease affects the saccadic eye movements system and, consequently, the motor behavior.

Both PD and aging led to drops in performance of drivers in the car simulator. Moreover, the underlying attentional mechanisms between older-drives and PD-drivers showed important differences. PD-drivers performed more gaze fixations, with larger variability, towards task-irrelevant areas of the visual scene and showed higher random gaze behavior, in attempt to increase the acquisition of information to overcome cognitive deficits provoked by the disease. Meanwhile, older-drivers restricted their visual search to the lane in order to detect threat-related stimuli for avoiding collision rather than keeping the vehicle speed. The current findings suggest that PD-drivers and older-drivers have a limited perceptual and motor driving ability compared to younger-drivers. These findings suggested that PD and aging differently influence drivers' gaze behavior in a simulated driving task. Considering that driving plays an important social role in the current society, more interventions should be implemented to improve the perceptual and motor abilities of people with PD and elderly people who intend to maintain as an active driver. The car simulators can be a safe environment to develop well-controlled practical strategies for these population, in order to reduce the number of collisions and to achieve safer driving. Eye movements analysis indicated that both the aging process and the PD impair the capture of task-relevant information in driving. Practical interventions aiming to boost visual abilities such as visual search accuracy and/or amplitude of saccades for both older- and PD-drivers should be considered.

Limitations of the research

Subjective data regarding participants' feelings and/or experience in driving a car simulator was not collected. Alternatively, it was informally asked for the participants their experience with driving in a virtual environment and how challenging the simulated task could have been. All participants, including the group of young adults, reported no previous experience with driving in a virtual environment (e.g., car simulators, racing video games) and/or no discomfort and difficulty in performing the task during the test. A familiarization procedure was done prior to the test in order to check whether or not participants would be able to follow the task instructions and show a stable driving behavior (i.e., total control of the vehicle's speed variation and steering, no difficulties in changing gears, and full domain with the simulator controls). In the present study, the essential characteristics of visual information provided by the virtual environment appeared to be quite similar to those available in natural driving (e.g., optic flow and perception of depth), allowing a realistic task-specific context for the participants. However, due to the short testing duration of 3 min, elderly drivers may not have had sufficient time to establish a stable driving behavior. The assessment of the perceptual-motor behavior of older- and PD-drivers in longer protocols will be addressed for further investigations.

Conflicts of interest: none.

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Table 1. Means (SDs) for characteristics of the participants (n=30). Disease duration, Hoehn and Yahr stage, UPDRS are non-applicable (N/A) for both young and older adults.

	Younger drivers	Older drivers	PD drivers
Age (years)	26.5 (3.1)	69.8 (3.4)	66.0 (6.0)
Weight (kg)	82.7 (17.1)	91.0 (8.4)	67.4 (16.3)
Height (m)	177.8 (6.3)	163.1 (6.8)	164.6 (5.9)
Disease duration (years)	N/A	N/A	6.7 (3.0)
Hoehn and Yahr stage*	N/A	N/A	2.2 (0.4)
UPDRS-III (pts)*	N/A	N/A	19.3 (6.1)
MMSE (pts)*	N/A	28.5 (1.1)	28.2 (1.8)

Note: UPDRS – Unified Parkinson's Disease Rating Scale; MMSE – Mini-Mental State Examination; * in ON-state of medication.

Table 2. Means (SDs) for the gaze behavior of each group across AOIs (n=30).

	Young drivers	Older drivers	PD drivers
Outside			
nFIX (units)	1.60 (2.17)	3.10 (3.28)	8.40 (8.93)
dFIX (s)	0.53 (0.81)	0.79 (1.23)	1.85 (2.19)
Lane			
nFIX (units)	274.10 (42.60)	307.70 (46.64)	388.30 (164.53)
dFIX (s)	130.38 (15.86)	149.33 (13.02)	126.25 (26.39)
Speedometer			
nFIX (units)	61.10 (24.71)	16.00 (11.76)	34.10 (37.06)
dFIX (s)	22.16 (12.19)	3.95 (3.20)	12.38 (16.30)
Rearview mirrors			
nFIX (units)	36.80 (18.93)	27.20 (19.24)	24.50 (21.22)
dFIX (s)	7.98 (4.69)	6.04 (4.27)	6.38 (8.32)

Figure 1 Caption: a) screenshot from Eye Tracker scene video (participants' view in the simulator) with the black cursor representing the eye position. AOIs: lane (red), speedometer (yellow), and rear-view mirrors (blue); b) screenshot from Eye Tracker eye video with the pupil cursor (black) and the corneal reflection cursor (white).

Figure 1 Alt Text: in the left side, a screenshot from the eye tracker scene video in which shows the car simulator layout used in the study. A black cursor is appearing in the picture in which represents participants' gaze location during the test. Fours colored squares are placed in the relevant sources of information: lane (red), speedometer (yellow) and three squares in each rearview mirror (blue).

Figure 2 Caption: a) Percentage of trial time driving in speed zone (%VEL), b) Coefficient of variation of the percentage of trial time driving in speed zone (%VEL-cv), c) Number of collisions (COL) and d) Coefficient of variation of the number of collisions (COL-cv) per group.

Figure 2 Alt Text: Four bars graphics plotting the driving performance variables with group factor in the horizontal axes and in the vertical axes the mean values at the left (figures A and C) and variability values at the right (figures B and D). Significantly differences between groups are showed in the mean values; in which young adults spent more time driving in speed zone than older adults and PD group, and showed fewer collisions than PD group.

Figure 3 Caption: A) Total number of fixations (nFIX), B) Coefficient of variation of the total number of fixations (nFIX-cv), C) total fixations duration (dFIX) and D) Coefficient of variation of the total fixations duration (nFIX-cv).

Figure 3 Alt Text: Four bars graphics plotting the overall fixations pattern with group factor in the horizontal axes and in the vertical axes the mean values at the left (figures A and C) and variability values at the right (figures B and D). Drivers with PD performed more fixations than older adults and with a higher variability than young adult; and performed shorter fixations than young adults, with a higher variability than young and older adults.

Figure 4 Caption: Visual entropy (bits) per group.

Figure 4 Alt Text: A bar graph plotting the visual entropy with group factor in the horizontal axis and the visual entropy in the vertical axis. Significantly differences are showed between drivers with PD and young adults drivers.

Figure 5 Caption: Heat map representing the relative density of visual activity for: a) younger-drivers; b) older-drivers; and c) PD-drivers. Cooler color (green) represents less visual activity while hot color (red) indicates the most time spent gazing towards the areas.

Figure 5 Alt Text: Three images from the final frame of the driving simulator when the experiment ended was used to plot the heat map for young-drivers, older-drivers and PD-drivers, respectively. The heat map represents the relative density of visual activity. Cooler color (green) represents less visual activity while hot color (red) indicates the most time spent gazing towards the areas.

Figure 1


Arquivo Exibir Reproduzir Navegar Favoritos Ajuda
Reproduzindo
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Arquivo Exibir Reproduzir Navegar Favoritos Ajuda
Reproduzindo
00:40 / 03:18

Figure 2

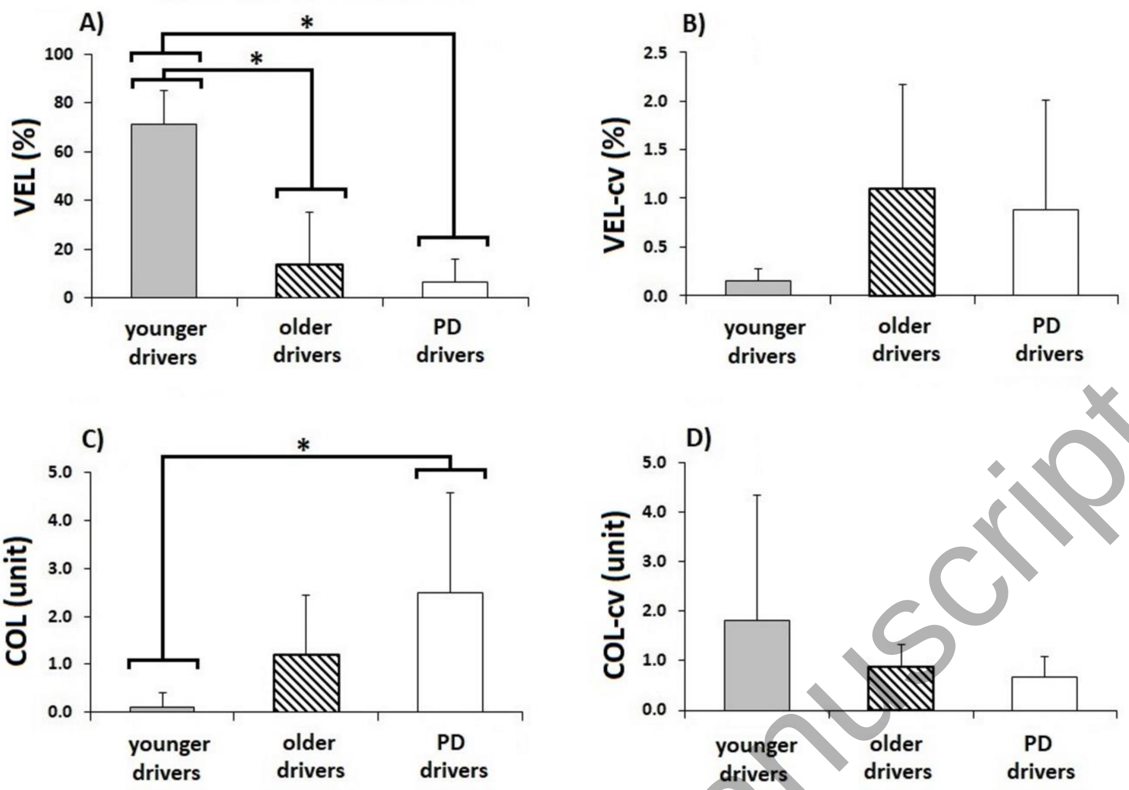
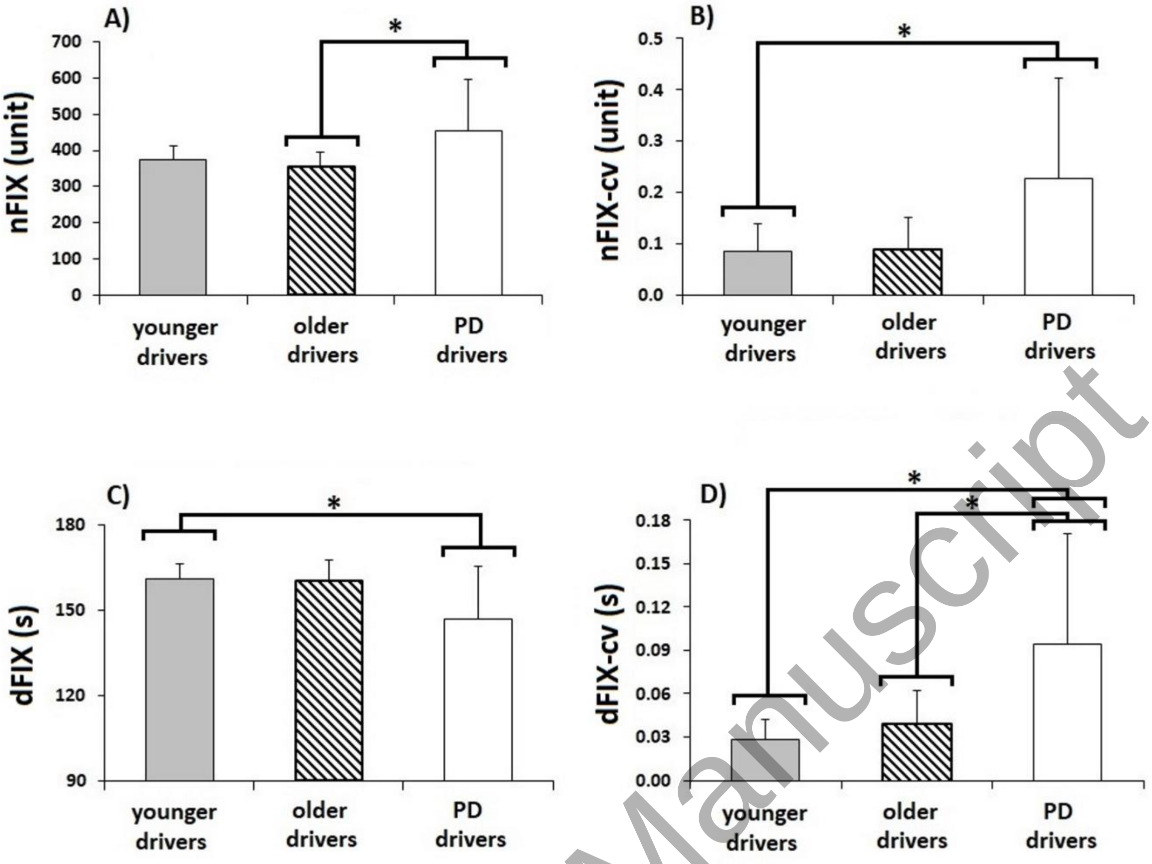
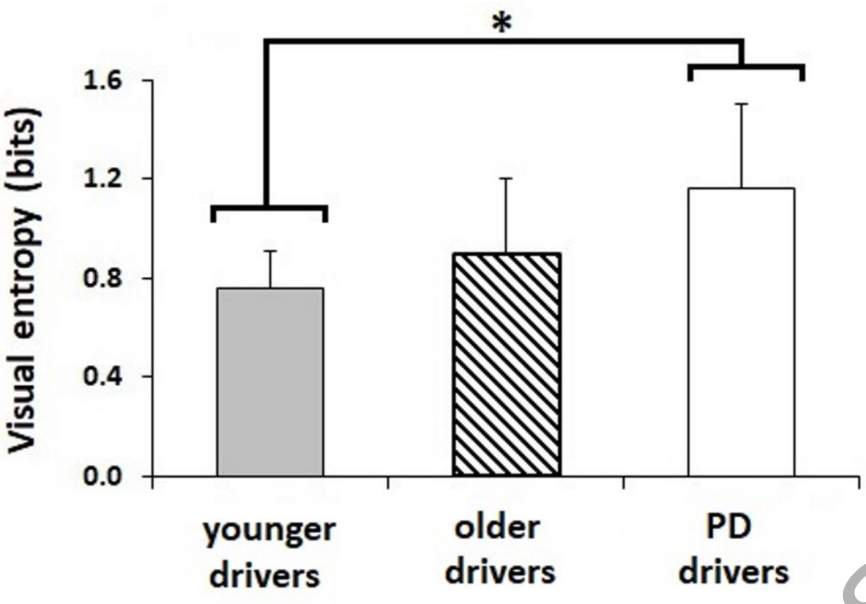

A)
*
*
100
80
60
40
20
0
VEL (%)
younger drivers
older drivers
PD drivers
B)
2.5
2.0
1.5
1.0
0.5
0.0
VEL-cv (%)
younger drivers
older drivers
PD drivers
C)
*
5.0
4.0
3.0
2.0
1.0
0.0
COL (unit)
younger drivers
older drivers
PD drivers
D)
5.0
4.0
3.0
2.0
1.0
0.0
COL-cv (unit)
younger drivers
older drivers
PD drivers

Figure 3



A)
*
nFIX (unit)
700
600
500
400
300
200
100
0
younger drivers
older drivers
PD drivers
B)
*
nFIX-cv (unit)
0.5
0.4
0.3
0.2
0.1
0.0
younger drivers
older drivers
PD drivers
C)
*
dFIX (s)
180
150
120
90
younger drivers
older drivers
PD drivers
D)
*
*
dFIX-cv (s)
0.18
0.15
0.12
0.09
0.06
0.03
0.00
younger drivers
older drivers
PD drivers

Figure 4



*
1.6
1.2
0.8
0.4
0.0
Visual entropy (bits)
younger drivers
older drivers
PD drivers

Figure 5