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Driver's visual perception as a function of age. Using a driving simulator to explore driver's eye movements in vertical signs

José Ricardo Gabriel Kuniyoshi [a], Alex Taima Costa [a], Aurenice Cruz Figueira [a], Felipe Issa Kabbach Jr. [b], Ana Paula C. Larocca [a,*]

[a] Department of Transportation Engineering, São Carlos School of Engineering, University of São Paulo, Brazil
[b] Department of Transportation Engineering, Polytechnic School, University of São Paulo, Brazil

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ABSTRACT

This research aims to evaluate the impact of age on the driver's attention and perception of road signs, using a driving simulator. The sample focused on drivers aged between 20 and 60 years, since this age range accounts for the largest number of qualified drivers - almost 75% of the total. As drivers gain more experience on the road, the more likely they are to drive safely and therefore, less likely to crash. However, many young and adult drivers become overconfident in their ability to drive and mistakenly believe they are driving safely. The sample studied was analyzed according to the following age groups: Group I, "young" drivers and Group II, "adult" drivers. The collected data included that from the eye tracking system (*SmartEye*) and questionnaires applied after the experiment. The test scenario replicated a 10 km stretch of a Brazilian highway were the gaze tracking data allowed the measurement of the following variables: observation time, maximum fixation time of signals and the number of signs observed. Both groups had excellent performances in the Simulator's Post-Drive Questionnaire, with an average correct rate of 94% for Group I and 89% for Group II. Regarding the data provided by *eye-tracking system,* Group II proved to be more attentive in perceiving speed signs, although in general, they needed to observe the speed sign for longer to be able to perceive it.

1. Introduction

Human factors play an important role in almost all traffic accidents resulting in serious injuries and fatalities, thus, research on how to improve driver behavior seems to be an obvious way to address this serious problem and to help mitigate it.

According to WHO (WHO, 2018), traffic accidents cause more than 1.35 million victims per year, this being one of the biggest causes of death in people up to 30 years old. In Brazil, only in 2019, 19% of those involved in accidents with fatalities were drivers aged between 18 and 30 years, accounting for 42% of the drivers aged between 31 and 60 years (Datatran, 2019).

Although practical driving skills can be quickly mastered, some (less obvious) skills, such as risk perception, require more experience (Isler et al., 2011; Wong et al., 2018; Chen et al., 2019; (Oviedo-Trespalacios et al., 2020). This means that the overconfidence of young and adult drivers makes them think they are in control when driving unsafely, and thus, they become more likely to take risks, since they believe their skills are improving (Clarke et al., 2006; Ross et al., 2016; Oviedo-Trespalacios et al., 2018; Nguyen-Phuoc et al., 2020).

Young drivers, in turn, are also overrepresented in accident statistics, compared to adult and elderly drivers. Young drivers under the age of 30, for instance, represent about a tenth of the population in OECD countries (Organization for Economic Cooperation and Development), however, they represent more than a quarter of drivers killed on the highways (WHO, 2018).

Thus, the need for further research on the behaviors of young and adult drivers remains evident. The purpose of this research is to evaluate how age influences their behavior when driving a vehicle on a driving simulator course.

2. Literature review

Most of the available studies focus on the alteration of cognitive

* Corresponding author.
E-mail addresses: ri2017gk@usp.br (J.R.G. Kuniyoshi), alex.taima@usp.br (A.T. Costa), aurefig@gmail.com (A. Cruz Figueira), felipe.kabbach@usp.br (F.I. Kabbach), larocca.ana@usp.br (A.P.C. Larocca).

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abilities with aging (Konstantopoulos et al., 2010; Hassan and Abdel-Aty, 2013; Desapriya et al., 2014; Feldstein et al., 2020). Erel and Levy (2016) reviewed articles about the impact of aging on cognitive functions, and found that some improve with age, while others remain the same, or even get worse. One of the negative impacts of aging is the reduction of visual attention (Erel and Levy, 2016). Drag and Bieliauskas (2010) summarized the research carried out on the physiological changes that occur as the human being ages and, from this, found that the levels of attention, such as short-term memory and associative memory, are negatively affected.

In the research by Pradhan et al. (2005), 72 participants, equally divided into three age groups (16 and 17 years old, 19 to 29 years old and 60 to 75 years old), carried out a test in a driving simulator with 16 different scenarios, while a gaze tracking system captured their eye movements. From the position of the eyes and the driving behavior, it was possible to determine if the driver was able to perceive risk situations or if their driving was imprudent (such as not stopping at a mandatory stop sign). It was determined that adult drivers find it easier to visually identify elements of the scenario, which are necessary to gather the information relevant to the assessment of potential risks.

Unlike the research by Pradhan et al. (2005), the studies by Ho et al. (2006) indicate that the effects of aging can be harmful in some traffic situations. In this study, 14 young drivers (between 18 and 30 years old) and 14 elderly drivers (between 54 and 79 years old) participated in the experiment. This consisted of an initial screen showing a specific traffic sign, followed by a series of scenes where the volunteers were asked to find the initial sign and determine whether it was "present" or "absent" by pressing the corresponding keys. Half of the scenes showed signs; the other half did not. The results indicated that elderly drivers had less precision (more errors) and longer reaction time, demonstrating that the difficulty in finding the signs in the scenes increased with age.

DeLucia et al. (2003) found that adult drivers have greater difficulty in making judgments about possible collisions compared to younger drivers.

One of the experiments carried out by Costa et al. (2018) was similar to that of Ho et al. (2006). In this case the volunteers observed an image of a sign for a period of time and subsequently had to select the respective sign on a modified keyboard containing 57 figures; if they made the correct selection, the time interval of the next sign shown in the screen would be shorter, if they made a mistake, the time would be longer. 100% accuracy was achieved when the image duration was 130 ms.

Ledger et al. (2019) compared young and elderly drivers and determined that most of the relationships between cognitive functions and driving performance did not present disparities between the two age groups. Thus, the study supports the idea that there is a similar relationship between cognitive functioning and driving performance in both age groups.

Based on data from traffic accidents, Ayuso et al. (2020) carried out a study on the impact that the increase in age can bring to the severity of accidents in Spain. The results indicated a relationship between the severity of traffic accidents and the age of the driver.

For the driving simulator experiment, it is essential to understand the possible side effects that the virtual environment can cause, in order to prevent drivers from feeling any discomfort during the test. In a study on the discomfort caused by virtual reality (Becker and Ngo, 2016), the volunteers watched videos of stereoscopic images of the inside of a moving vehicle. The focus of the research was to study the user's discomfort due to "motion sickness", which is the feeling of dizziness and nausea caused by repeated movement, either real or apparent (Hosseini et al., 2015), the latter being the case of the driving simulator. Motion sickness has also been addressed in other studies, such as that by VENKATAKRISHNAN et al. (Venkatakrishnan et al., 2019).

Table 1
General data of the sample of volunteers who participated and completed the experiment.

	Total	Group I	Group II
Number of volunteers	23	15	8
Male/female ratio	2.71	3.25	1.67

Fig. 1. Driving simulator used for the experiments.

3. Materials and methods

3.1. Participants

The criterion for selecting volunteers was made randomly, through adverts on social networks and in the university's own bodies. The only requirement was for the individual to have a National Driver's License. The volunteers were divided into two groups: Group I, consisting of those between 20 and 27 years old (M = 21.59; SD = 1.87), while Group II consisted of volunteers between 41 and 61 years old (M = 53.00; SD = 6.16). Further details of the sample are provided in Table 1. During the data collection phase, it was found that the older age group had a greater tendency to present motion sickness symptoms. Thus, the data corresponding to these volunteers was discarded.

3.2. The driving simulator

The fixed-base high steering driving simulator used in this research belongs to the Department of Transport Engineering (STT / EESC) of the São Carlos School of Engineering (EESC / USP). It is a human-in-the-loop type of equipment used for the analysis and observation of the driver's behavior in the simulated road environment and attempts to resemble a real world driving experience (Larocca et al., 2018). The three main components of this driving simulator are: the hardware, the software and the eye tracking system. The simulator is shown in Fig. 1.

3.2.1. Hardware

The driving simulator consists of a cockpit with a car seat equipped with a Logitech G27 wheel that provides steering wheel torque while driving and counts with a six-speed gear shift lever, interlocking accelerator, brake and clutch pedals. The projection system consists of a *DepthQ HDs3D2* projector (with 1080p resolution and a 60 Hz refresh rate) and a projection screen with a 1425 mm wide by 800 mm height format, positioned in front of the driver and providing a very wide visual field of 120 degrees in the horizontal plane and 50 degrees in the vertical plane. The central screen positioned in front of the driver had a resolution of 1.70 arc min/pixel (Larocca et al., 2018).

The processing system is integrated by three high-performance

Fig. 2. Highway simulation example.

computers. Simultaneously, each computer performs exclusively one of the following processes: modeling and visual generation of the virtual environment, modeling of vehicle dynamics and control of the eye tracking system.

3.2.2. *Software*

The driving simulator used in this research consists of two software: the *Vi-CarRealTime* software –developed by Vi-Grade® and marketed in Brazil by the Multicorpos® company, and the *Virtual Test Drive* package developed and marketed by Vires®. The *Vi-CarRealTime* software is responsible for both, real-time vehicle simulation in the environment and vehicle dynamics. The purpose of the *Virtual Test Drive* package is to carry out the modeling and simulation of the virtual environment of the driving simulator.

The driving simulator's software and hardware allow the interaction of the virtual environment with the driver, since they enable the generation and update of the scene displayed on the simulator screens in front of the driver, in addition to the execution of the desired situations, traffic control, changing vehicle parameters, among other factors. Fig. 2 presents an extract of the scenario generated by the software.

3.3. *The eye tracking system*

The Eye Tracking System, developed by the company *SmartEye*, consists of four cameras and a screen that displays the highway scene at a frequency of 60 Hz. The system processes the images received in real time and indicates the point on the screen corresponding to the driver's focus of attention, by detecting the position of the pupil.

Three of the four cameras are monochromatic and positioned in front of the driver, 15° below the eyes, at a distance of 1 m from the face and 40 cm from each other. In addition, all three cameras count with 8 mm lenses. In this manner, it is possible to capture the position of the pupil with an accuracy of 2° within a visual field of 50° in the horizontal plane and 30° in the vertical plane, with at least two cameras, during the driving time. The fourth camera, positioned behind the driver, is colored and counts with a resolution of 480p. This camera records the simulated scenario from the perspective of the driver's visual field, at a frequency of 25 Hz.

The system software defines a coordinate system and locates the four cameras, the driver's eyes and the projection screens. Thus, the points of intersection of the plane containing the screen and the vector defined by the gaze, obtained through the orientation of the pupil detected by the three cameras, are calculated. The fourth camera is responsible for transforming the points of intersection obtained into pixels, in such a way that the driver's gaze is transmitted in the form of video. This allows to determine the number of times the driver detects road traffic signs, the moment and the time interval at which this happens. Fig. 3 illustrates how the coordinate system is defined.

Finally, the MAPPS program was used to analyze the video generated by the eye tracking system. Through this software, the scenario's regions

Fig. 3. Eye tracking system.

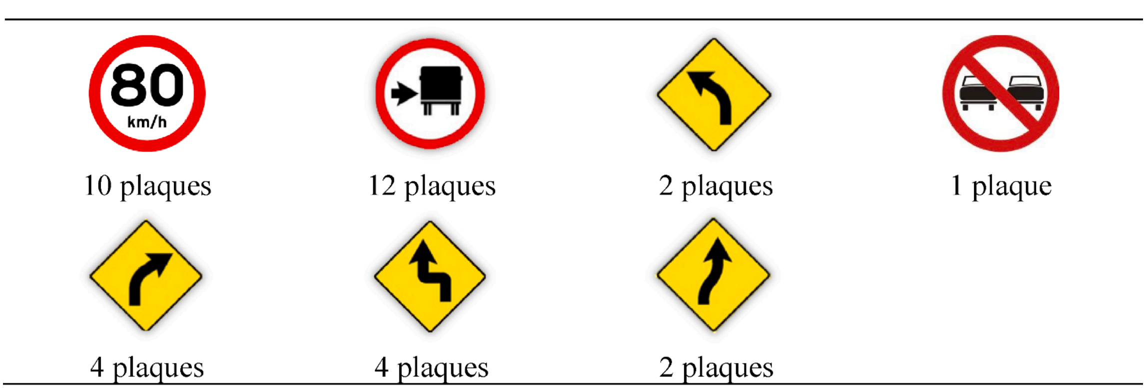


Fig. 4. Signalization present on the stretch.

of interest (ROI) can be defined, demarcating the vertical signs or points of interest, in order to measure the times and duration of driver's eye fixation for these locations.

3.4. Extract under study

The virtual scenario used in the present research corresponds to a stretch of a Brazilian highway of approximately 10 km long.

The section under study presents a sinuous outline, with 20 curves along the extension, many of which have a radii of less than 150 m. In the section in question, the guiding speed is 80 km/h, and the road's cross section consists of three lanes, with a total of 10.50 m wide.

The section's signalization includes d35 plaques (excluding the tourist signs) which are divided into seven categories: single right (A-2a) and left (A-2b) turn warning, Right sharp turn warning sign (A-5b), left sharp turn warning sign (A-4a), speed limit sign (R-19), heavy vehicles keep to the right sign (R-27), no overtaking sign (R-7). It is importance to highlight the difference between the concepts of sign and plaque: the sign is the information transmitted to the driver, whilst the plaque is the physical element that presents the sign (Larocca et al., 2018). Fig. 4 shows the six types of signs present on the stretch.

The speed signs are arranged in pairs, one on the right and one on the left, at 5 locations along the highway. In order to facilitate their identification, the plaques were named in accordance with the kilometer they are located on the highway and their position (right or left).

3.5. Study variables

More detailed descriptions of the variables collected in the experiment are detailed below (Larocca et al., 2018).

Observation Time: total fixation time on a sign;
Maximum Fixation Time: duration of the longest fixation on a sign;
Number of plaques observed: number of signs for which fixations longer than 100 ms occurred;
Percentage of visualization: quotient between the number of drivers who perceived the sign and the total number of drivers who participated in the experiment.

There are several studies that address cognitive changes associated with aging. Cantin et al. (2009) analyzed how mental processing influences the performance of different age groups when driving a vehicle. Drag and Bieliauskas (2010) argue that the progressive decrease of attention and memory with aging can hinder the handling of complex situations, such as driving a vehicle.

Thus, in addition to analyzing the variables related to fixation on signs, it is pertinent for the present study to perform an evaluation of the influence of the driver's attention and memory, in order to determine whether there are disparities between the age groups. To this end, a questionnaire about the level of attention and memory will be applied to each volunteer after completing the course.

3.6. Experimental procedure

3.6.1. Driving simulator route

Prior training of volunteers in the simulator is a recommended practice adopted in studies with driving simulators, before the experimental phase of data collection (Stoner et al., 2011; Rangel, 2015; Ledger et al., 2019). Therefore, the volunteers were asked to complete a training scenario of between 5 and 10 min duration, in order to adapt to the driving simulator controls and become familiar with experiment tasks. Before starting the experiment, the drivers were asked to drive normally.

3.6.2. Questionnaire on the level of attention and memory

Based on an adapted version of the questionnaire by Costa et al. (2018) and Ho et al. (2006), after completing the experiment, the volunteers were invited to answer a questionnaire in which they were asked to mark the signs that appeared whilst driving, as well as inform the speed allowed on the road. This questionnaire contained the images of 16 different plaques, of which only a few were present on the route. The aim was to analyze the change in short-term memory according to age in order to determine how this affects driving behaviors (Drag and Bieliauskas, 2010).

Table 2
Perceptions of the groups in the questionnaire.

Questionnaire			Results	
Signalization	Plaque	N° of times present on the road	Correct selection (%) Young drivers	Correct selection (%) Adult drivers
Stop		None	94.12	100
No parking		None	100	100
Right turn		4	100	87.5
Left turn		2	100	87.5
Heavy vehicles keep to the right		12	94.12	100
No changing traffic lanes from right to left		None	94.12	100
School zone		None	100	100
No heavy vehicles		None	100	100
Two-way traffic ahead		None	100	100
Risk of falling rocks		None	100	100
Left sharp turn		2	94.12	100
Rigth curve		2	82.35	87.5
Pedestrians crossing		None	100	100
Crossroads ahead		None	100	87.5
No overtaking		1	52.94	12.5
Slippery road		None	94.12	75
Overall Average			94.12	89.06

3.7. Statistical analysis

First, a descriptive analysis of the results was performed. This type of analysis aims at synthesizing a series of values of the same nature, allowing a global view of their variation. The data was synthesized by means of tables, graphs and descriptive measures, such as position and

Table 3
Number of volunteers in each group who perceived each speed sign and the respective percentage of visualization.

Signalization	Young Drivers		Adult Drivers	
	N° of volunteers who perceived the sign	Visualization percentage	N° of volunteers who perceived the sign	Visualization percentage
km 5 – Right	11	73.33%	7	87.50%
km 5 – Left	8	53.33%	2	25.00%
km 10 – Right	11	73.33%	7	87.50%
km 10 – Left	4	26.67%	2	25.00%
km 15 – Right	9	60.00%	7	87.50%
km 15 – Left	3	20.00%	2	25.00%
km 20 – Right	5	33.33%	7	87.50%
km 20 – Left	7	46.67%	3	37.50%
km 25 – Right	7	46.67%	7	87.50%
km 25 – Left	9	60.00%	6	75.00%

dispersion measures. Heat maps were used, as well as the principal component analysis (PCA) graph, to better represent the variables related to the fixation time (Abdi and Williams, 2010).

In relation to the statistical inference aspect, for the binomial variables, the Fisher's exact test was used to compare proportions. The variables of observation time and maximum fixation time were subjected to the Shapiro-Wilk normality test, if they presented a normal distribution, a two-way ANOVA test would be performed (Padovani, 2014). Alternatively, if the data did not present a normal distribution, a non-parametric analysis would be performed using the Mann-Whitney U Test.

4. Analysis and discussion of results

4.1. Questionnaire on the level of attention and memory

By analyzing the general results of the questionnaire, it was found that the performance of both groups was similar. The volunteers' good performance was mainly due to correctly indicating the signs that were not present on the route.

Regarding the road's speed limit, 94% of the volunteers in the young drivers group managed to remember the value (80 km/h), while everyone in the adult drivers group was able to answer correctly. As for the other signs, the performance of each group in the applied questionnaire is shown in Table 2.

Linear regression of the data was performed and the correlation coefficient between the correct selection and the age of the volunteers was calculated ($R^2 = 0.1069$; $p = 0.1107$ and $\rho = -0.3488$). An adequate linear relationship could not be established, given that both the correlation coefficient and the determination coefficient resulted in relatively small values.

On the other hand, when placing a No Overtaking sign (R-7) on purpose, although the scenario consisted of a dual carriageway stretch of highway, the participants' performance was well below average, especially for adult drivers, where only one volunteer noted the presence of this sign.

In the group of young drivers, 53% of the volunteers perceived the No Overtaking sign (R-7) while in the group of adult drivers, only 12.50% did. Statistically, a significant difference is observed in the Fisher's exact test: $\alpha < 10\%$ and $p = 0.88$. It may be an indication that, even without certainty, the participant intuitively judged, by the characteristics of the road, which sign was more likely to be present. All volunteers in the group of adult drivers have had a National Driver's License for more than 20 years, which reinforces the hypothesis that the experience of adult volunteers has made it possible to predict the road signs.

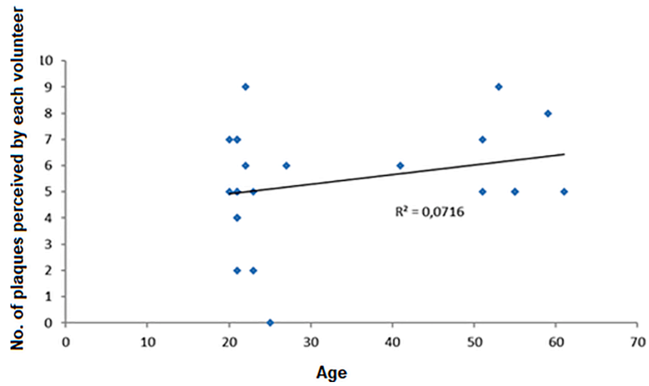


Fig. 5. Scatter plot of individual performance.

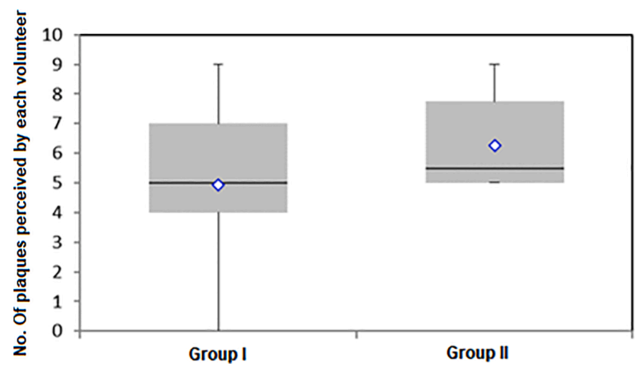


Fig. 6. Box Diagram of Number of Plaques Observed.

4.2. Number of speed signs perceived by each driver

Table 3 shows the number of volunteers from each group that perceived each speed sign, as well as the respective percentage of visualization.

Individual performance was plotted on a scatter graph (Fig. 5). In addition, the correlation coefficient between the number of plaques perceived by each volunteer and their age was determined to be insignificant ($\rho = 0.268$).

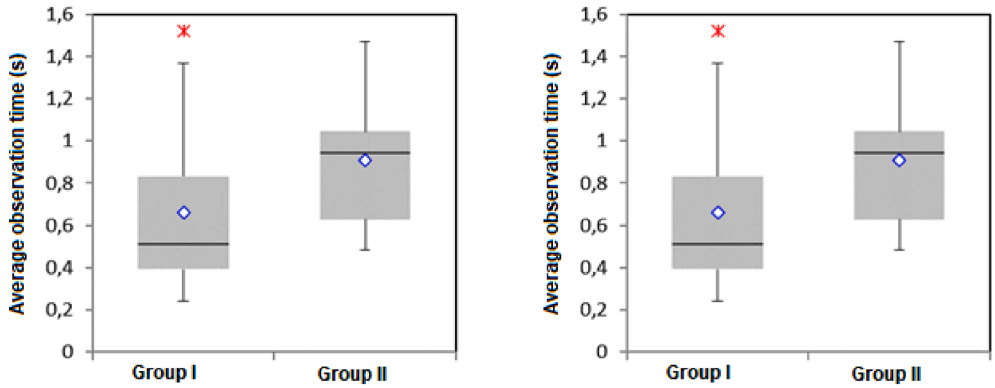
The box diagram (Fig. 6) indicates that adult drivers tend to perceive a greater number of speed signs. In order to prove this hypothesis, the Mann-Whitney U Test was performed ($U1 = 90$, $U2 = 30$, $U_{critical} = 33$ and $p = 10\%$), resulting in a statistically significant difference.

4.3. Observation time and maximum fixation time on speed plaques

For the analysis of descriptive statistics, box diagrams were plotted (Fig. 7) to perform an initial evaluation of the results. To this end, the maximum fixation time and the average observation time were considered, which was calculated as the average of the observation times of all the speed signs seen by each volunteer.

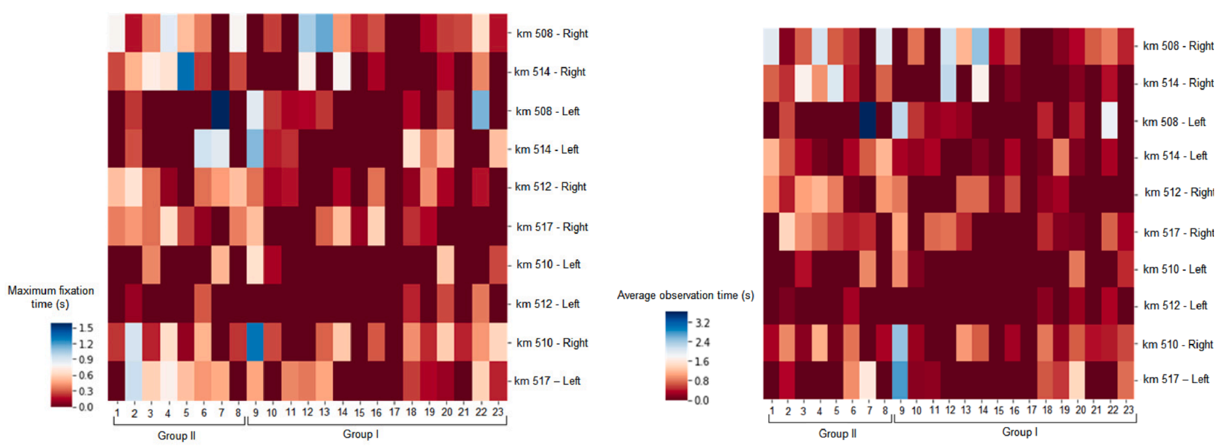
By analyzing the box diagrams, it can be observed that there is a tendency for the observation time of each speed sign to be longer for adult drivers. It is important to highlight that the observation time was not considered for volunteers presenting fixation times of less than 100 ms in any speed sign plaque.

The performance of the groups was also represented by means of heatmap graphics (Fig. 8), produced with the Seaborn package in the Python 3 programming language, with a Jupyter interface. The function



(a) (b)

Fig. 7. (a) Average Observation Time Box Diagram and (b) Maximum Fixation Time Box Diagram.



(a) (b)

Fig. 8. (a) Heat map of maximum fixation time and (b) Heat map of observation time in each plaque.

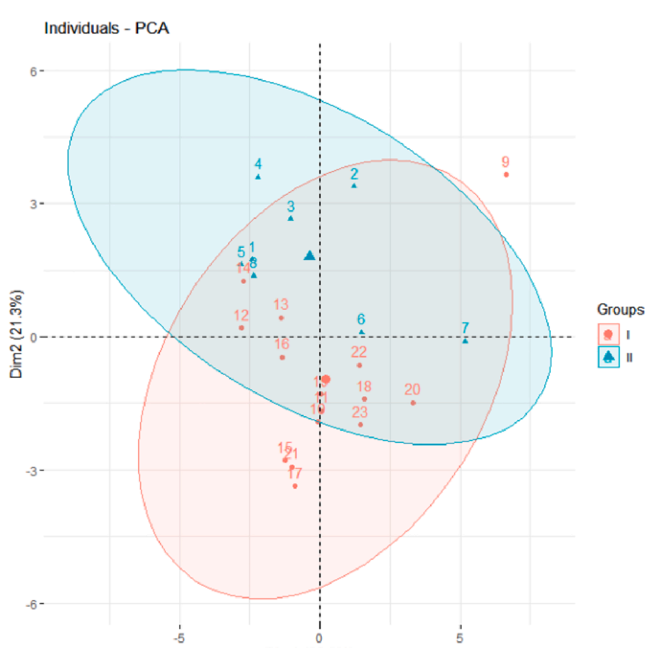


Fig. 9. PCA of the Variables Related to Fixation Time (Observation Time and Maximum Fixation Time).

used was seaborn.clustermap (). In the graphs, volunteers from group II are represented on the left (1-II to 8-II), and those from group I, on the right (9-I to 23-I). The bluer, the longer the plaque fixation time of the volunteer, and the redder, the shorter the time. Light tones indicate intermediate times.

In addition, multivariate statistical methods were used to facilitate data interpretation. The PCA aims at promoting a linear transformation of the data so that the results of this transformation present their most relevant components in the first dimensions.

In the present work, the PCA analysis was performed based on the observation time and maximum fixation time for each of the signs seen by each of the volunteers. The signs for which the fixation time was less than 100 ms were disregarded from this analysis.

The PCA was performed by means of the *FactoMineR* package in the R 3.6 program, whilst the graph (Fig. 7) was produced with the *fviz_pca()* function. The confidence ellipses indicate that any point has the same probability of being inside it, with a 95% significance level, as it is usually adopted.

In Fig. 9, the points correspond to the volunteers. Drivers belonging to the Group I are represented in pink, and in blue, drivers belonging to Group II. The two dimensions represent the entire variation of the samples, considering all variables. Through the graphic analysis, it can be observed that volunteers 15 and 21 had very similar results, since their points are close to each other. On the contrary, volunteer 9 had very different results from volunteer 17, since their points are further away. The box diagram indicated that, through the PCA, volunteer 9 is

Table 4
Shapiro-Wilk test results.

	p-value	
	Observation Time	Maximum Fixation Time
km 5 – Right	0.004	0.047
km 5 – Left	0.000*	0.000*
km 10 – Right	0.002	0.047
km 10 – Left	0.000	0.000*
km 15 – Right	0.003	0.047
km 15 – Left	0.000*	0.000*
km 20 – Right	0.000*	0.000*
km 20 – Left	0.000*	0.000*
km 25 – Right	0.003	0.019
km 25 – Left	0.011	0.047

*$p < 0.001$.

an outlier of the group of young drivers

Although the circles are partially overlapping, there is an indication of grouping, that is, there is a greater similarity between the results of volunteers belonging to the same group.

Subsequently, the Shapiro-Wilk test was applied in order to determine whether the data presented a normal distribution. The p-values were adjusted using the Holm method, which serves to avoid false positives. The data analyzed corresponded to the observation time and the maximum fixation time on each plaque. Table 4 shows the p-values obtained for these tests.

All p-values are below 0.05, thus, we assume that the data presents a non-normal distribution. This inhibits the application of the two-way ANOVA test to infer whether there are distinctions between groups.

Consequently, a non-parametric analysis was performed, evaluating the average observation time only. The Mann-Whitney U Test ($U1 = 83$, $U2 = 29$, $Ucritical = 31$ and $p = 10\%$) indicates that this difference is statistically significant.

5. Conclusion

The present research had as main objective to analyze the influence of age in the performance of drivers, by means of tests carried out in simulated driving environments. To this end, data was collected through the *SmartEye* eye tracking system and the application of a questionnaire. In general terms, there were no major disparities between the group of young drivers and the group of adult drivers.

Regarding the application of the Post-Driving Questionnaire, which evaluated the level of attention, the performance of the volunteers was, in general, highly satisfactory, with a correct selection rate above 94% for the group of young drivers and above 89% for the group of adult drivers. However, when analyzing the no overtaking sign that, intuitively, would not be present on a dual carriageway, the performance of both groups was evidently poorer than the average of correct answers. This indicates that the drivers tend to use their experience to predict road signs, that is, the volunteers indicated what they believed was more coherent instead of focusing on their experience on the scene.

The group of adult drivers obtained more satisfactory results regarding the percentage of visualization in relation to speed signs, which could be verified by the non-parametric statistical tests. This is in accordance with the studies carried out by Pradhan et al. (2005), since the results of the present research also demonstrate that adult drivers find it easier to visually identify important elements of the scenario in order to acquire information.

CRediT authorship contribution statement

José Ricardo Gabriel Kuniyoshi: Funding acquisition, Investigation, Methodology, Writing - original draft, Writing - review & editing. **Alex Taima Costa:** Data curation. **Aurenice da Cruz Figueira:** Conceptualization. **Felipe Issa Kabbach:** Conceptualization, Funding acquisition. **Ana Paula C. Larocca:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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