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Impact of the geometric field of view on drivers' speed perception and lateral position in driving simulators

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Abstract

Driving simulators have become an effective tool in road safety research. In recent years, the validity of simulators raised debates concerning the extant to which driving in the simulator resembles driving in the reality. Different types of driving simulators with different characteristics have been developed to study driver behavior, however, the fidelity and reliability of such systems are questionable if no proper validation is conducted. Regarding the visual aspect, the fidelity of the simulators can be assessed based on the field of view of the simulator screens. Drivers' speed perception and lateral position were compared for two different geometric field of view (GFOV) angles (i.e., 60 and 135 degrees). Results from the ANOVA tests showed that drivers highly underestimate their driving speed while driving for the condition with 60 degrees of GFOV compared to the condition with 135 degrees of GFOV. Furthermore, drivers drove closer to the real-world situations in the condition with 135 degree of GFOV compared to the condition with 60 degree. Results of this study suggest that, using incorrect GFOV for any simulator would generate biased results in speed and lateral position. Therefore, a proper calibration criterion of the GFOV for the simulators is essential. This study recommends using a scale factor (GFOV/FOV) of 1.00 for virtual environment offered by the simulation scenarios such as GFOV of 135 degree for simulators having three screens with 135 degree of field of view (FOV).

Keywords: driving simulator; field of view; geometric field of view; driving speed; vehicle lateral position

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1. Introduction

Many recent studies supported the reliability of driving simulators for evaluating drivers' behaviors particularly in road safety and management aspects [1, 2]. Researchers have always attempted to deeply investigate the impact of newly proposed treatments on driving behavior. The investigation process can be carried out using different tools and techniques. One such tool is the driving simulator, which is used for observing driver behavior represented by different variables such as speed, acceleration, deceleration, and spacing in the created virtual environment. These driving simulators offered a cheap and safe approach to verify the effectiveness and side impacts of different treatments of traffic control systems and road designs. The fidelity of driving simulators has raised questions that, to what extent driving in the simulators could resemble driving in the real-world. In a systematic review by [3], authors classified the fidelity of driving simulators by allocating ratings based on three measures, i.e., the physical design, dynamics, and visual aspects. In terms of physical rating, a low fidelity is a computer-based simulator with a keyboard or joystick, while a high fidelity is a simulator with full vehicular cab and full control. For the dynamics rating, a low fidelity simulator is static with no motion and a high-fidelity simulator is a simulator, which is based on a full motion plate. Regarding the visual aspects, the fidelity rating is based on the field of view (FOV). FOV is the visual angle produced from the driver's perspective and is dependent of the size of the simulator screens. A low fidelity simulator is equipped with a single PC screen, while medium fidelity simulator has a multiple screen with FOV less than 180 degrees. A high-fidelity simulator has projector screens with FOV of more than 270 degrees.

Geometric field of view (GFOV) is defined as the overall environment (road and roadside objects) displayed to the drivers on the simulator screen(s). A ratio of GFOV to FOV (i.e., GFOV/FOV) is called a scale factor, which is a significantly important parameter to be considered in driving simulator related studies [4]. GFOV is the adjustable parameter of the virtual environment offered to the drivers on available screens [5, 6]. If GFOV is modified to be larger than the FOV, the displayed scene on the screen(s) would zoom out and would offer larger displayed scene than the real world [5]. In contrast, if GFOV is lower than the FOV, the displayed scene would zoom in towards the driver and would display smaller area than the real-world environment. Such cases may compromise the accuracy of driving behaviors between the real world and simulators. Therefore, to ensure correct perception of drivers' travelling speed, driving simulation scenarios should offer to the driver a high degree of realism by choosing the correct GFOV.

The correct perception of the travel speed by drivers is important for safe driving behavior [7, 8]. Roadside elements such as roadside signs, streetlights, trees and other road users could help drivers in perceiving their travel speed in a better way. A recent study investigated the combined effect of three roadway design elements (guardrail existence, shoulder width, and roadway curves) on speed perception. It was reported that, these roadway design elements can be useful in reducing driving speed [9]. However, the same study highlighted that sharp curves could make drivers difficult in maintaining their lane position. Another study that evaluated the impact of the positions of delineation poles on speed perception have discovered that, as the lateral distance of the delineation poles was increased, drivers tended to overestimate their traveling speeds [10]. Furthermore, research based on driving simulator shows that in general the traveling speed is underestimated in the simulation environment [1, 11].

Few studies can be found in the literature, which investigated the impact of GFOV on speed perception. Colombet et al. [4] investigated the effect of GFOV on speed perception using a dynamic driving simulator with a cylindrical screen of 150 degrees of FOV. Five different scale factors (GFOV/FOV) were used ranging from 0.7 to 1.3. A total of 20 participants were asked to provide their perceived traveling speeds for 50 and 90 kph. Results showed that the perceived speed was increased with the increased scale factors.

In another study, Mourant et al. [6] used a fixed base simulator with a 45 degrees image projected on a curved screen to investigate the impact of GFOV on drivers' speed perception. Thirty subjects participated in their study and they were asked to drive for two speeds of 30 and 60 mph with three different settings (i.e. GFOV of 25, 55 and 85 degree). However, the authors did not include a GFOV of 45 degree, which would be used as a control setting for their study. The results from their study show that speed perception is significantly influenced by the GFOV i.e. the higher the GFOV the lower the value of the estimated speeds. Moreover, it was found that drivers estimated the 60 mph speed most accurately when the GFOV was 55 degrees. However, for the speed of 30 mph, participants estimated the speed most accurately when the GFOV was 85 degrees.

Another study also investigated the effect of GFOV on drivers' speed perception using a driving simulator with wide FOV of 210 degrees [5]. Sixteen subjects participated in their experiment. The subjects were asked to provide their perceived speed on a rural and urban road environment for four different speeds with four different GFOV/FOV ratios. Authors reported that with a ratio of 1.0, speed was underestimated with an average of 10%. Moreover, small ratio of 0.83 showed more speed overproduction while high ratio showed a reduction in the error of speed production. The authors suggested the results from their study could be helpful for simulators having wide screen with wide FOV of more than 180 degrees.

In all studies mentioned above, the effect of GFOV on lateral position has not been investigated. Lateral position is an important parameter and that could be affected by the changes in field view of simulation scenarios. Therefore, it is important that the simulation scenarios should offer such an environment where drivers' speed perception and lateral position are not unrealistic but closer to the real-world drivers' behavior. To the best of our knowledge, the effect of changes in GFOV on lateral position has not been studied yet. In this study, we focus not only on the drivers' speed perception but also the lateral position that may change due to the variations in field view of the simulation scenarios. Furthermore, this study examines four different requested speeds (i.e., 50, 70, 80 and 100 kph) with two different GFOV settings (i.e., 60 and 135 degrees).

The aim of this study is to investigate the impact of different GFOV angles on drivers' speed perception and lateral position. The outcome of this study would allow practitioners to use appropriate GFOV for calibrating medium fidelity driving simulators. The first objective is to evaluate the relation of different GFOV inputs with drivers' speed perception for different requested speeds. Moreover, the second objective is to investigate which of the GFOV inputs allow drivers to maintain lateral positions that are closer to the real-world behavior.

2. Methods

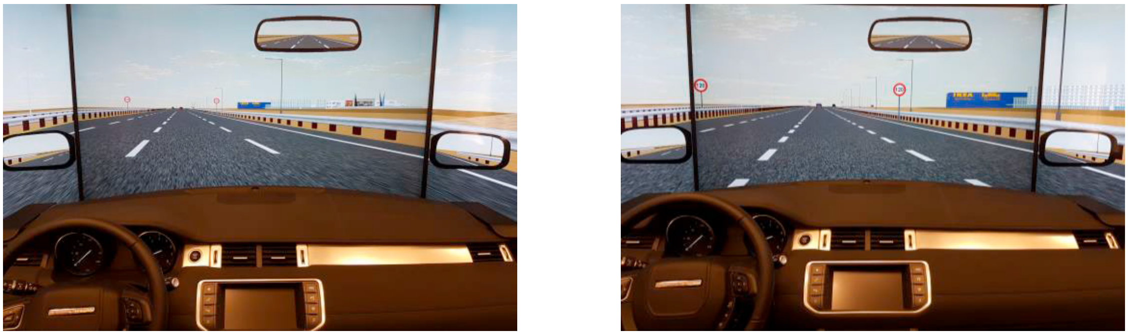
2.1. Participants

A total of 41 participants, having a valid driving license in the State of Qatar participated in the study. The driving population in the state of Qatar is characterized by a multi-cultural driver background [12]. The participants were informed in advance to avoid eating or drinking anything (except water) at least two hours before the start of the experiment. The is the minimum requirement to overcome simulation sickness during the experiment [13]. Out of the 41 participants, one was affected by simulation sickness, data was missing for other three participants, and one participant was considered as an outlier. This left us with the final number of 36 participants (29 males and 7 females). These participants were representing 15 different countries with a mean age of 30.7 (± 8.6 SD) years, and their ages ranged from 20 to 55 years old. Regarding driving experience, the mean value was 9.1 (± 6.6 SD) years and ranged from 1 to 31 years.

2.2. Apparatus

The study was conducted using a fixed-base medium fidelity driving simulator located at Qatar Transportation and Traffic Safety Center lab at Qatar University (Figure 1). The driving simulator is composed from two main units i.e., the driving unit and three large screens. The driving unit is consisted of a Range Rover Evoque cockpit (fixed-base) having automatic transmission gear box, pedals, indicators, steering wheel with force-feedback and speedometer. The three large screens have a 135 degree of horizontal FOV with a 60 HZ refresh rate and a high resolution of 5760 x 1080 pixels. The two units of the simulator are interfaced with STISIM Drive 3 and CalPot32 software, which provides high speed graphics with a sound processing system. This simulator has been validated in

Figure 1. Installed driving simulator at Qatar University (Range Rover Evoque)



a) 135 degree of GFOV b) 60 degree of GFOV

Figure 2. Simulation displays with different configuration of GFOV

a recent study for both the external (i.e., actual speed & speed perception) and subjective validity [1].

2.3. Road segment

To collect data on speed perception for four different requested speeds, it was appropriate to design two road segments i.e., a segment of the Doha expressway with the speed limits of 120 kph and a local road parallel to the expressway with speed limit of 80 kph. This was done with a reason to allow drivers to drive on the expressway for the higher requested speeds (R-speeds i.e., 80 and 100 kph), while on a local road for the lower R-speeds (i.e. 50 and 70 kph). Two driving scenarios were replicated from two real world situations (i.e., Doha expressway and a local road) based on the google earth images and video footages.

Two different configuration files were created with a 60 and 135 degrees of GFOV adjusted in the display setting parameters of STISIM interface. Each scenario was run twice for each participant i.e. one with configuration file of a 60 degree of GFOV while the other with configuration file of a 135 degree of GFOV. Figure 2 differentiates the simulation environments between both configurations at the same lateral/longitudinal position of the simulator car.

2.4. Experimental Procedure

After obtaining the Qatar University's Institutional Review Board ethical approval (QU-IRB 609-EA/6), participants were recruited by spreading official emails to Qatar University staff, faculty and students. The experimental session took about one hour including the simulator driving tasks, pre and post-test questionnaires. In general, the experiment was organized as follows:

1. Each participant was welcomed, and was asked to sign an informed consent form. The consent form provided information about the rights of using the collected data for research purposes. Moreover, it provided information about simulator sickness and the right to abort the experiment if needed.
2. Pre-test questionnaire was provided to each participant to collect information such as sociodemographic background, traffic knowledge and driving experience.
3. Before the start of the experiment, following instructions were provided to each participant: "In this experiment, your speed perception will be judged. You will be driving on Doha expressway with speed limit of 120 kph and a local road with speed limit of 80 kph. You will be asked several times to drive with a specific speed and your speedometer will be disabled. When you feel that you have reached the requested speed say "YES" to confirm".
4. Each participant was given a trial drive to get familiar with the driving simulator and its driving control.
5. After that, each participant drove two test drives with two different GFOV angles "Condition", i.e., 135 and 60 degrees. For each GFOV angle, four speeds were requested "R-speed", i.e., 50, 70, 80 and 100 kph two times from each participant "Trial". Participants were given a drive on the expressway to estimate their speeds for 80 and 100 kph while a drive on a local road to estimate for 50 and 70 kph. This means that each participant drove sixteen requested speeds for the two test drives (i.e., 8 for GFOV of 135 and 8 for GFOV of 60). The two GFOV angles and the four requested speeds were all randomized to reduce bias in the experiment. The responsible

experimenter was sitting on the driving simulator control station to instruct the participants. Upon any confirmation from the participants on the requested speed, the exact time values were recorded, which were used to extract the estimated values later on.

6. After the experimental drives were finished, participants' feedback on the driving experience in the simulator was collected through a post-test questionnaire.

2.5. Data collection and analysis

In this study, data was collected for speed and lateral position using STISIM Drive® Software. Data for speed and lateral position was extracted from the recorded exact time values. For each R-speed (50, 70, 80 and 100 kph), there were two GFOV conditions (135 and 60 degrees). Participants drove twice for each GFOV and R-speed. Therefore, a repeated measures Analysis of Variance (ANOVA) test was conducted on each variable of interest (i.e., mean speed and lateral position) for the factors, i.e., R-speed (4) x Condition (2) x Trial (2). A p-value of 0.05 was set for the statistical significance.

3. Results

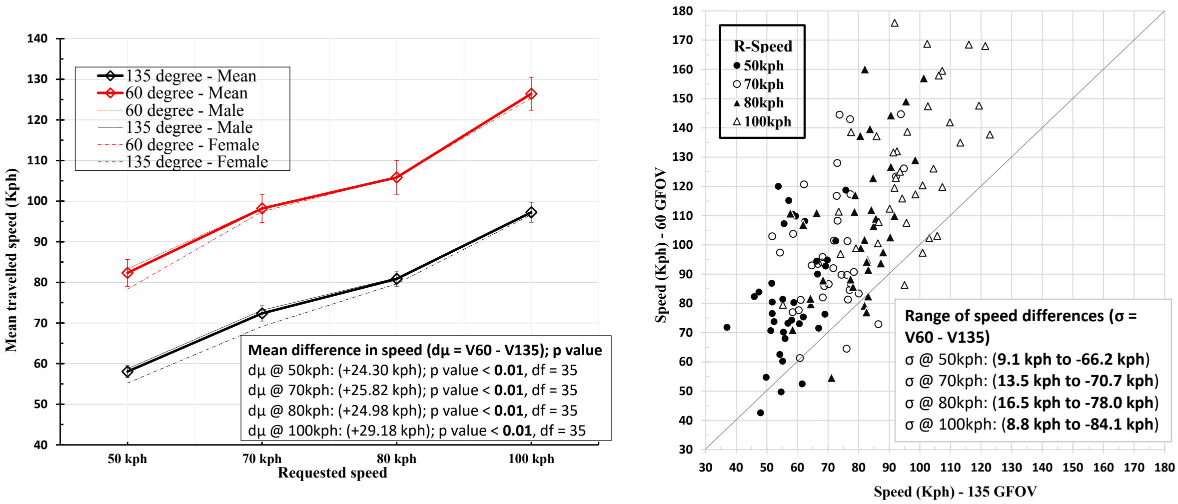
3.1. Analysis of speed

Table 1 shows the results from the analysis of variance (ANOVA) for the variable of interest "perceived speed". The main effects of 'Condition', 'Trial and 'R-speed' were significant independent of other factors. This means that there was a significant difference in drivers' speed perceived for the 135 and 60 degrees GFOV (i.e., Condition), the first and the second drive (i.e. Trial), and the four requested speed of 50, 70, 80 and 100 kph (i.e., R-speed). Furthermore, the two-way interaction effect of "Condition x Trial" was also significant meaning that the drivers' perception of their travelling speed for each requested speed was significantly different between both drives. However, no other significant interaction effect was observed from the analysis. The results from ANOVA test can be shown in Figure 3a), presenting the average travelled speed values estimated by the participants for both GFOV by separate lines. It shows that for all the requested speeds, participants underestimated their travelling speeds and drove faster for the 60 degrees compared to the 135 degrees of GFOV. The differences in the mean speeds travelled for all the requested speeds between the two GFOV angles are more than 20 kph. Furthermore, Figure 3a) presents mean speed profiles comparing gender for both GFOV angles separately. The respective mean differences in speed between male and female are not significantly different i.e. condition with 135 degree of GFOV (t-test: paired/two-tail, p value = 0.40, df = 286) and condition with 60 degree of GFOV (t-test: paired/two-tail, p value = 0.68, df = 286).

A scatter plot is presented to understand the individual speed estimation values for both GFOV angles (see Figure 3b)). Drivers' traveling speed values for each participant and for each requested speed were plotted as a series of coordinates (X = 135 degree of GFOV, Y = 60 degree of GFOV). It can be seen from the figure that most of the drivers drove faster in the condition with 60 degree compared to the condition with 135 degree of GFOV (points located above the diagonal line). Comparing the individuals' values with the requested speeds, most of the drivers underestimated their travelling speed and drove faster than the requested speed in the condition with 60 degree (points located above the respective horizontal line of each requested speed). On the other hand, drivers' speed was better distributed and was comparatively closer to the requested speeds in the condition with 135 degrees of GFOV (points located to the right or left of the respective vertical lines of each requested speed). As expected, the range of speed

Table 1. Analysis of variance – ANOVA test (Greenhouse-Geisser) for mean estimated speed.

Effect	*F*	*dfs*	*P*
Trial	9.8	1, 35	**.003**
Condition	76.4	1, 35	**<.001**
R_speed	252.7	2, 64	**<.001**
Trial x Condition	7.5	1, 35	**.01**
Trial x R_speed	1.1	3, 91	.33
Condition x R_speed	1.7	2, 82	.19



a) Mean speed profiles for Condition by separate lines (bars represent standard error)

b) Scatter plot with estimated speed for 135 degree of GFOV on x-axis and for 60 degree of GFOV on y-axis

Figure 3. Analyses of mean and individual speed values

differences (σ = V60 – V135) are higher towards the negative values showing that the travelling speed was highly underestimated for condition with 60 degree of GFOV compared to the condition with 135 degree.

3.2. Lateral position

Table 2 shows results from the ANOVA test for the lateral position. The results show a significant main effect for the factors ‘Trial’ and ‘Condition’ independently. This means that independent of any other variable, drivers’ lateral position was significantly different between both drives (i.e., Trial), and two GFOV angles (i.e., Condition). Moreover, the results show that the effect of the factor ‘R-speed’ is not statistically significant meaning that the lateral position was not affected by the four requested speed.

Figure 4 shows profiles of the mean lateral position for the two GFOV angles (separate lines) and the four requested speeds (separate points on horizontal axis). The lateral position on the y-axis is the lateral distance between the centerline of the traveling lane and the center of the simulator vehicle. The figure shows that for all requested speeds participants’ lateral position was away by 20 to 30 centimeters from the lane centerline for the 135 degrees GFOV. In addition, for both GFOV, this distance from the lane centerline decreases with the increase in driving speed.

Furthermore, Figure 4 shows the comparison of our results with three other real-world studies of which two studies extracted lateral position from video footages i.e. Blana and Golias [14] and Lennie and Bunker [15], while one study was based on observations from GPS data, i.e., Wang et al. [16]. The studies reported lateral position in different ways (e.g., the distance from the left tire of the vehicle to the left edge of the lane), so for the purpose of identical comparison the reported values for available speeds were manipulated to represent the distance between the centerlines of a traveling lane and a vehicle. The ranges of lateral position varies from 10.9 to 35.5 centimeters for 50 – 100 kph, while from 20.9 to 35.5 centimeters for the 70 – 100 kph speed regimes.

4. Discussion

This study aims at investigating the fidelity of speed perception and lateral position considering different GFOV angles in a medium fidelity driving simulator. The fidelity of speed perception and lateral position was assessed for two different GFOV having scale factors of 0.44 and 1. The scale factor of 0.44 was chosen for the comparison because this was the accurate GFOV recommended by STISIM help manuals for simulators having a single screen. The study targets an important issue of using the default incorrect 0.44 scale factor for simulators containing more than one screen. The results from this study clearly show that using incorrect GFOV in driving simulator studies would generate

Table 2. Analysis of variance – ANOVA test (Greenhouse-Geisser) for lateral position

Effect	*F*	*dfs*	*p*
Trial	5.8	1, 35	**.021**
Condition	14.2	1, 35	**.001**
R_speed	1.4	3, 91	.24
Trial x Condition	1.1	1, 35	.29

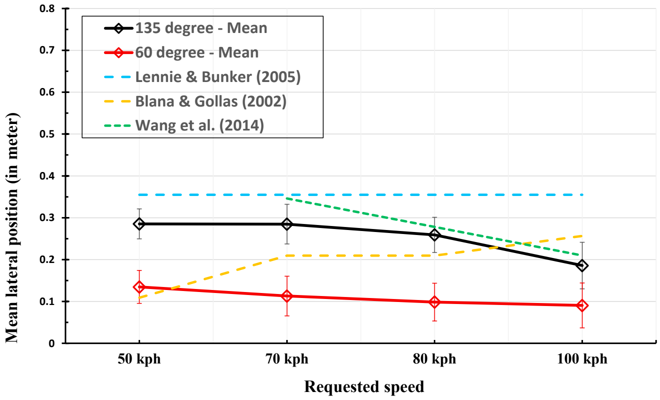


Figure 4. Mean lateral position profiles for Condition by separate lines (bars represent standard error)

biased results. Therefore, an appropriate validation of speed perception of driving simulators is essential. Hussain et al. [1] recommended the validation process of driving simulators not only for actual speed but also for the speed perception.

The results from the ANOVA test showed that drivers' perceived speed was significantly affected by the GFOV conditions, trials and requested speeds, independently. Drivers significantly underestimated their speeds for the 60 degrees GFOV angle with an approximately constant difference in mean speed across all requested speeds compared to the 135 degree of GFOV. For the 60 degree of GFOV (i.e. scale factor of 0.44), participants underestimated their travelling speed and drove much faster than the requested speeds. The mean differences in the speed between the two GFOV was even more than 20 kph for all requested speeds. This is consistent with the results of a previous study that explained that for the lower scale factor values, drivers highly underestimate their traveling speed [5]. A possible reason for this underestimation could be that while reducing the GFOV the virtual environment of the simulation scenario would stretch and would make the frontal objects nearer to the drivers. Furthermore, this would eliminate the objects from the drivers' peripheral vision. Therefore, the replaced objects in front would move slower; hence, this could result in speed underestimation.

Regarding lateral position, the results from ANOVA test showed that drivers' lateral position was significantly changed due to factors "Trial" and "Condition". Compared to the condition with 60 degree of GFOV, participants' lateral position in the condition with 135 degree of GFOV was closer to the results of the real world studies as visualized in Figure 4. In particular, the lateral position profile for 135 degree of GFOV has a similar tendency to the real-world observations from GPS data collected by Wang et al. [16]. This finding explains the importance of using an accurate GFOV value for simulation scenarios in order to collect data that is more realistic and similar to the real world. On the other hand, participants drove closer to the lane centerline while driving for the 60 degrees of GFOV. This might be because of the zoom in phenomenon of the virtual environment (including the road surface), allowing drivers to drive in the middle of the lanes. Therefore, the results also indicate the importance of the height of car in the virtual environment of the simulator, and the distance of the driver's seat from the simulation screens. Moreover, the results showed that the lateral position decreased as the requested speed increased for both conditions. This indicates that drivers tend to drive on the lane centerline as they travel faster.

Despite the value of this research, certain limitations should be taken into account. The study was carried out inviting a limited number of test subjects. The driving simulator used in this study was a fixed base medium fidelity simulator. Furthermore, the speed perception and lateral position was compared for only two levels of the GFOV. For that reason, investigating the drivers' performance under more levels of GFOV will provide more insights on the optimum settings of driving simulators.

5. Conclusion

This study evaluated the impact of GFOV on driving behavior (i.e., speed perception and lateral position). Two different GFOV angles (60 and 135 degrees) were tested for four different speeds (i.e., 50, 70, 80 and 100 kph). The results showed that using an incorrect GFOV in driving simulators would generate bias in speed perception. Drivers underestimated their traveling speed while driving in the 60 degrees of GFOV. Furthermore, the variation in drivers' lateral position was closer to the real-world observed behaviour in the condition with 135 degrees of GFOV, compared to the condition with 60 degrees of GFOV.

In conclusion, this study recommends appropriate validation and calibration processes of any simulator, before conducting any study related to speed, derivatives of speed and lateral positions. Furthermore, based on the results regarding lateral position, future research should be conducted on the effects of the height of the virtual environment in the simulation scenarios, as well as the position and distance of the cockpit seat from the simulation screen.

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