Subjective Assessment of Commercially Common Input and Display Modalities in a Driving Simulator

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Abstract: Driving simulators could be valuable tools for better understanding human behavior while driving. The latter has the potential to guide the design of roads and vehicles. In addition, studies of driving habits can help gain insight into the relationship between human attention and locomotion. A critical aspect of a driving simulator involves the right choice of stimulus presentation and interaction methodologies. This paper presents a driving simulator study that evaluates a series of commonly used display and steering devices in terms of usability, physical and cognitive task load, and simulator sickness indices. Specifically, conventional large display, commercially available head-mounted display, and various steering devices were compared. Our study used two steering devices (stationary and wireless) and a gamepad controller to control the simulated vehicle. We hypothesize that using a Head-Mounted Display (HMD), although suitable for inducing immersion, might come with the cost of possible simulator sickness and a decrease in driving performance. We analyzed the individual and combined impact of display and steering input device types on our subjective metrics measurements. Our results proved our hypothesis on higher perceived immersion for HMD based driving simulator. Also, the paper highlights the trade-offs between big monitor setup and Virtual Reality (VR) in terms of workload and fatigue.

1 INTRODUCTION

VR is a class of graphical user interfaces that generates an immersive, spatially realistic, and interactive environment that could be both experienced and interacted with using head-mounted stereo goggles, multi-projected installation, headphones, peripheral suits, and gloves (Brey and Søraker, 2009). The use of VR has been prevalent in both empirical research and industry for various operational tasks such as driving, surgical procedures, and work with machinery. Historically, multi-projected installations such as CAVE™ systems were the most commonly used in VR (Cruz-Neira et al., 1992). Such installations require sizeable physical space, a separate tracking system, and integration of input devices. Nowadays, HMD are highly preferred since they still provide binocular stereo vision, with head and hand track- ing already Incorporated into a head-worn system. The advantage of using VR for training and operating purposes is the ability to simulate and replicate hazardous and realistic situations in a controlled manner, where the possibility of endangering the users is either diminished or eliminated. For example, driving simulators place the driver in an artificial environment to recreate a real driving experience that is conducted safely and in a controlled manner. The driving simulator could be used not only for training purposes but also to provide insight into driving performance, road design, and assessment of human behavior under different circumstances, such as the influence of substances and severe weather and lighting conditions (Chang, 2016). Therefore, to account for human behavior during driving, we need to understand what display types and interaction modalities are most appropriate when designing driving simulators for an average user. Consequently, this study examines the impact of utilizing VR based dis- plays (HMD and large TV screen) and VR controllers (wireless and stationary steering wheels and conventional game controllers) on subjective metrics related to driving performance. We

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specifically analyze the effect of these interaction and display methods (combined and individually) on human behavior and self- reported, driving-related metrics.

The rest of the paper is structured as follows: First, we review the literature related to driving in terms of concepts of driving simulators, VR simulations, task-dependent human behavior, evaluation of steering and proposed methods, the fidelity of interaction and stimulus, and bodily/cognitive task load.

2 RELATED WORKS

Driving performance metrics might include the time to interact (move/rotate) with the device or the higher-level measurements like negotiating bends or the ability to adjust the steering after perturbations. For example, Fitts' law is a predictive model proposed to design interfaces to generalize involved factors. It states that the time required to move a pointer to a target area is dependent on the distance to the target divided by the area of the target (Fitts, 1954). Accot et al. (Accot and Zhai, 1999) developed a trajectory-based testing paradigm as a study scenario in parallel with Fitts' positioning task. Their pro- posed steering law can predict completion time relative to tunnel (path) parameters (such as length and width), which could be used as a tool for assessing trajectory-based tasks. Yet, control of a vehicle in- volves the ability to steer to negotiate bends at high speeds and take the right trajectory along the curved road (Kountouriotis et al., 2015). Van Leeuwen et al. (van Leeuwen et al., 2015b) investigated how driving performance and gaze behavior change through- out the time a novice driver's driving skills progress. A driving simulator was used to evaluate performance and gaze activity as participants practiced driving. They showed that improvement in the driving performance can be tracked and is correlated with the gaze activity and its changes throughout practicing using the driving simulator. They also showed that horizontal gaze variance could be used to predict an increase in speed. To quantify the trajectory of steering, multiple processes have been proposed (Hedegaard et al., 2019, Sportillo et al., 2017). Hedegaard et al. (Hedegaard et al., 2019) used angular deviation, which is the difference between a steering input signal and an average of all input signals to evaluate the steering performance across different steering modalities. They also quantified the smoothness of steering by using the frequency of significant peaks of the steering input signal. On the other hand, Sportillo et al. (Sportillo et al., 2017) used the number of steering turns as an indicator of steering stability after regaining control of a simulated vehicle. In our works, we will assess the steering performance to analyze the impact of display and input fidelity on the stability of a vehicle's trajectories while negotiating bends in two urban and rural environments and also to acquire gaze-steering coordination, which is a good indicator of driving performance and level of engagement with the control of a vehicle.

The degree of realism in a simulator is referred to as "physical fidelity" (van Leeuwen et al., 2015a). According to mentioned definition, physical fidelity could be defined for multiple aspects of simulation that include stimuli presentation (display, audio, field of view, texture quality, etc.), input methods, and interaction with the simulated content. To elicit realistic responses from participants while performing tasks like driving, we need a certain level of physical fidelity of the stimuli. However, according to (van Leeuwen et al., 2015a), there are several drawbacks to high fidelity simulation, which include: higher fidelity, the experiment will face a large number of variables to be controlled during the conduction of the experiment; Simulator discomfort, which can cause participants' withdrawal and reduced data quality; and, realism and high fidelity of certain types of visual information might be unnecessary or even distracting to evoke realistic performance from the participants. As a result, we need to address both the impact of display or interaction fidelity solely or combined. Van Leeuwen et al. (van Leeuwen et al., 2015a) in their study, implemented three levels of visual fidelity for a driving task experiment to evaluate the lane-keeping and gaze strategies adopted by participants. They demonstrated that the highest fidelity scenario resulted in higher steering activity, driving speed, and horizontal gaze variance compared to medium and low fidelity scenarios. Also, their driving simulator study addressed the impact of visual fidelity on curve negotiation, gaze behavior, and self-reported discomfort. They used three levels of visual fidelity (high fidelity with texture, mid-range fidelity without textures, and low-fidelity with only lane markers). They showed higher steering activity on the straight road, higher speed, and a higher degree of gaze variance for the high-fidelity scenario compared to the other two scenarios. It is not enough to address the impact of fidelity of only display or interaction method on driving; it is also important to analyze the complex effect of fidelity of display and input modality combined. McMahan et al. (McMahan et al., 2012) addressed the independent and compound effect of display and interaction fidelity on participants' performance in a VR first-person shooter game using a six-sided CAVE system. They showed that the compound effect of low fidelity and high fidelity for both display and interaction could significantly improve the in-game performances (completion time, damage taken, etc.). This effect could be associated with familiarity with those combinations (low or high fidelity for display and interaction), which resembles the standard desktop FPS games and real-life experiences. In the current study, we examine the compound impact of physical fidelity in terms of field of view, which is presented in the form of HMD based and display-based stimuli presentation (display fidelity), and input methods, presented here in the form of controller-based methods and realistic commercial steering devices (input fidelity) on driving-related performances, and also on perceived levels of immersion, sense of agency, cognitive and physical task load, and simulator discomfort.

An important aspect of a simulation is the mental and physical effort the users need to engage with the environment and interaction modalities. *Cognitive task load* is the total amount of user's mental demands required to use a specific system (Luxton et al., 2016) and *workload*, according to (Hart and Staveland, 1988), is defined as the perceived relation- ship between the number of available resources and the required amount by a given task. Various surveys can be used to quantify the cognitive and bodily task load. For example, the most commonly used survey is the NASA Task Load Index (NASA TLX), which is a self-reported measure of workload (Hart and Staveland, 1988). It evaluates the task load along six axes: mental demand, physical demand, temporal demand, effort, frustration, and self-performance. Although NASA-TLX was initially designed for pilots of space flights, it has been adapted for other environments and tasks such as surgery and driving activity. For example, Kountouriotis et al. (Kountouriotis et al., 2015) examined the impact of cognitive load on steering performance. Their study evaluated the effect of attention on steering performance in a simulated driving task. They used gaze fixation points (as a contributor to the cognitive load) that their position was either changing relative to the vehicle or was fixed relative to the vehicle. Their result indicated that the gaze fixations that were not analogous to the future path cause steering biases. Furthermore, Harris et al. (Harris et al., 2020) discussed the additional factors that are needed to be incorporated into the current workload measures for VR tasks. These factors include a degree of immersion, perceptual challenge, and methods to control the environment. In this work, we use NASA-TLX, simulation sickness, and a usability questionnaire (that includes items related to immersion, overall satisfaction and excitement, and fatigue in involved body parts) tailored for our specific VR task to evaluate users' experience of driving in VR.

3 METHOD

The present work aims to evaluate the impact of display and steering input methods on driving-related fidelity for subjective and objective measures. The study also explored the relationship between eye-hand coordination in driving, control of the vehicle's trajectory, and perceived sense of immersion, fatigue, and cognitive and bodily effort. The present study follows a within-subject design with two independent variables (display type and controller type) that formed six blocks. These blocks included all possible combinations of two display options (large display and HMD) and three steering devices (stationary steering device, wireless steering device, and manual controller). The main task included driving through a series of designated paths that involved driving straight and turning right and left. In all three possible instructions, participants were asked to control the steering and velocity of the virtual vehicle through an intersection and then either continue straight, turn right, or turn left. Each trial ends when a participant reaches a designated endpoint. Trials took place in two distinct virtual scenes (urban and rural characteristics) with an equal amount of turns in each scene. Consequently, each block consisted of twelve trials that had two variables of scene type (urban and rural), driving instruction type (straight, left, right), and two repeats. To test the impact of each scenario block, we collected the participants' subjective assessment of simulation discomfort, immersion, and task cognitive and physical workload by using questionnaires after each block. Gaze movements and steering activities were recorded during driving tasks, and we discuss them in a separate report. We hypothesized that: A higher degree of immersion will be experienced in the HMD scenarios, regardless of the input method. And less physical discomfort and simulation sickness would be experienced using the steering wheel (stationary and wireless) scenarios.

3.1 Participants

The present study includes 18 participants (5 female and 13 male), all over 18 years old ($M = 20.6 \pm 3.5$). With all of them having previous driving experience and 8 participants who had prior experience with VR. Written informed consent was obtained from all participants following a protocol approved by the Institutional Review Board at NJIT. Participants were asked to report any proneness to cybersickness or prior experience of dizziness with VR. One participant was excluded from the experiment and performing the tasks.

3.2 Stimuli

This experiment has used costume-made software developed with Unity 3D software (Haas, 2014). At the start, participants' ID and input device, and display type are set, and before the onset of the main scene, the calibration scene is presented. We also had a neutral scene for training, which we let participants try before the start of each to familiarize them with the control of the vehicle using the block's input device. If participants had already trained with a given input device in a subsequent block, we skipped the training session (a total of four times of running the training scene). The calibration scene was the standard calibration process provided by the Pupil Labs eye tracker add-on for unity. The driving tasks of the experiment took place in two scene types - urban and rural scenes. The urban scene included intersections in a city model (Manufacture), and the rural scene features a rural area with a roundabout in the center of the virtual scene. Both scenes included active pedestrians, but only in the urban scene, participants could cross the intersection. In the HMD-based blocks, instructions were shown on the speedometer and car dash- board monitor. Instructions were presented on the speedometer for the monitor-based blocks due to the fixed camera position. Also, both scenes included an intersection (a roundabout for the rural scene) where participants were instructed to perform the driving task (right and left turns and driving straight) on them. Both scenes include pedestrians, but only in the urban scene do they cross the road, depending on the traffic light.

The platform used for the experiment was a PC (six cores Core i7 3.7 GHz, Nvidia GTX 1070). Two steering wheel devices were Logitech G920 (for PC) (Logitech, 2015) as the stationary steering wheel setup, and Hyperkin S Wheel Wireless Racing Controller (Hyperkin, 2019) as the wireless steering wheel setup. Both devices feature hand pedals that we used to control of the vehicle. For the manual control as the input method, we used 6-DoF HTC VIVE controllers (Corporation, 2018) and Xbox one controller (Microsoft) respectively paired with HMD and large monitor scenarios. A 42 inches 4k TV, and HTC VIVE Pro VR headset (Corporation, 2018) were used for the large display scenarios, and the HMD-based scenarios, respectively.

3.3 Procedure

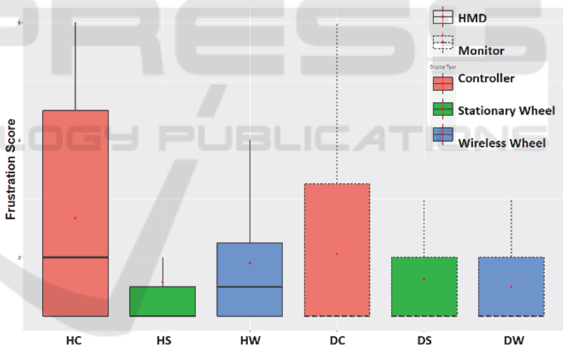
Upon arrival, each participant was given a consent form and a short study description. Participants were strongly encouraged to read the provided documents, ask questions, and express any concerns before signing the consent document. This was followed by a short demographic questionnaire and a simulation sickness questionnaire. Then participants were exposed to six experimental blocks in random order. Before the start of each block, participants were provided with a short trial scene to familiarize themselves with the input/display modalities of the block. After participants were comfortable with steering with the provided controller for the trial, an experimental block would start. At the beginning of each block, users' gaze was calibrated based on Pupil Labs' mobile eye-tracker and VR add-on. The calibration was a non-invasive process that required users to stare at five fixation targets for a predefined amount of time. After all points were collected, an experimenter was presented with an accuracy index. If the index was be- low 0.9, the calibration procedure was repeated. If the calibration procedure had failed after three trials, the experiment for that participant was terminated. During the block, the participant was presented with 12 trials. Participants were instructed to finish a driving task for each trial within the block. We terminated the trial if participants crashed the vehicle to the sides of the road, or in the case of the urban scene, also crashing with the virtual pedestrians caused the trial termination. After finishing each block, participants were provided with usability, simulator sickness, and NASA task load questionnaires (TLX). Each experiment was followed by a debriefing session.

3.4 Data Analysis

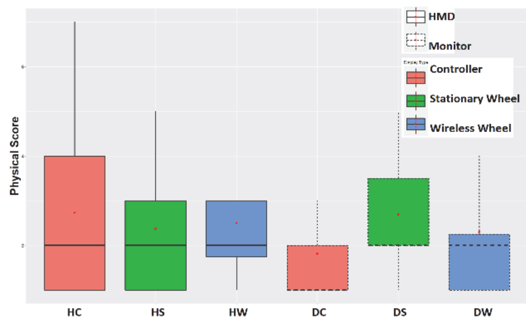
NASA Task Load Index (NASA-TLX) included six questions on a designated seven-point Likert scale. R programming language was used to import the cumulative data for statistical analysis. We used raw scores from each section to determine the significance of differences between the six experimental blocks. The usability questionnaire (table 1) used in this study included 30 questions that cover physical comfort, aspects of game-play like accuracy and control of the task, immersion, sense of presence, and sense of control over the task. All answers were available seven-point Likert scale responses. Scores were ordinal data without the assumption of normality. Simulator Sickness Questionnaire (SSQ) used in this study included the assessment of 15 symptoms that range from general discomfort to specific symptoms like nausea and sweating. Each symptom had a four-level response that included none, slight, moderate, and severe. For the analysis of subjective data scores, with regards to block specifications, we used R and (Kuznetsova et al., 2017) package to perform a mixed model analysis of the relationship between task load, simulator sickness, and usability scores, separately, and input and display modalities of the driving block. As fixed effects, input and display types with interaction terms in the model were used. As random effects, we had intercepts for participants. *P*-values were obtained by likelihood ratio tests of the full model with effects in question against the model without the effect in question.

4 RESULTS

The usability questionnaire questions were split into three sections: questions related to the overall satisfaction of the experiment, questions related to the sense of immersion and presence, and those associated with physical comfort. This discrimination is due to the contextual similarities of the questions and similar relationships with the display and input scenarios. Results of the mixed model analyses for the usability questionnaire items revealed that the choice of input device significantly impacted 19 out of 30 questions, and 18 out of 30 questions were predicted by the display type (for concrete results, see table 1). However, no significant effect of interaction between display type and input device type on any of the usability questions has been observed. Among five usability questions related to the overall satisfaction of the experience and enjoyment (Q18 to Q22 table 1), satisfaction or enjoyment of the experience, sense of accomplishment, and suitability of task to gameplay increased by the two steering devices (stationary and wireless). However, excitement with experience increased by HMD and steering devices. The score of all questions related to the sense of immersion, presence, and engagement with the virtual environment (Q1 to Q12 from table 1) increased for the scenarios with HMD display and steering wheels in comparison to a large monitor and gamepad controller. The only exception is the perceived picture quality (Q12, table 1), which showed the highest scores for conditions with monitor display. For the fatigue-related and physical comfort items (Q13 to Q17 of table 1), fatigue in the wrist and fatigue in neck decreased for the monitor display blocks, fatigue in fingers decreased for the steering devices, and overall physical comfort enhanced for the monitor-based scenarios, and comfort with the viewing position increased for the steering devices. For the NASA task load scores, the interaction effect of display and input impacted the physical score ($\chi^2(2) = 6.31$, $p = 0.04$), the interaction of monitor display and stationary wheel input increasing it by 1.16 ± 0.47 (Likert scale score), and monitor display and wireless wheel input increasing it by 0.82 ± 0.47 (figure 1b). Also, the interaction effect of input and display types affected performance score ($\chi^2(2) = 11.11$, $p = 0.004$), monitor display and stationary wheel lowering it by 1.69 ± 0.55. Lastly, in- put type impacted the frustration level ($\chi^2(2) = 8.19$, $p = 0.01$), stationary wheel input lowering it by 1.07 ± 0.39 (figure 1a). From simulator sickness related scores, we observed a significant effect of input de- vice type on the general discomfort level ($\chi^2(2) = 6.53$, $p = 0.038$). Level of the fatigue was impacted by the input device type ($\chi^2(2) = 7.02$, $p = 0.03$). Self reported headache induced by the trial blocks was significantly affected by the type of display ($\chi^2(1) = 6.26$, $p = 0.01$), and also by the input device type ($\chi^2(2) = 6.98$, $p = 0.03$), but no interaction effect was observed.



(a) Frustration level scores of NASA TLX across experimental blocks.



(b) Physical task load scores of NASA TLX across experimental blocks.

Figure 1: Compound effect of the input device and display type on frustration level and physical load of NASA TLX questionnaire based on experimental blocks.

Table 1: Results of the mixed model analysis of the effect of the input and display modalities on the usability items. Impact of display and/or input modality on each score is indicated according to the likelihood ratio (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$).

		Display			Input		
	Usability Question	*p*-value	χ^2	Df	*p*-value	χ^2	Df
Q1	Rate your sense of immersion	***	20.56	1	***	24.37	2
Q2	Rate your sense of being in the virtual environment	***	17.42	1	**	10.73	2
Q3	How much did it seem as if you could reach out and touch the objects or people you saw	***	17.42	1	**	10.73	2
Q4	How often when an object seemed to be headed toward you did you want to move to get out of its way	***	17.42	1	**	10.73	2
Q5	To what extent did you experience a sense of 'being there' inside the environment you saw	***	16.90	1	*	6.28	2
Q6	How often did you want to try to touch something you saw	***	16.9	1	*	6.28	2
Q7	How involved was the experience	***	14.28	1	***	16.93	2
Q8	How completely were your senses engaged	***	18.44	1	***	14.03	2
Q9	To what extent did you experience a sensation of reality	***	20.95	1	**	10.62	2
Q10	How engaging was the experience	***	17.81	1	***	22.27	2
Q11	Overall, how much did touching the things and people in the environment you saw/heard feel like it would if you had experienced them directly	***	17.81	1	***	22.27	2
Q12	How was the picture quality during the experience	***	13.30	1	2.93	0.23	2
Q13	Rate your physical comfort level after your experience	*	5.07	1	0.08	4.91	2
Q14	Rate your soreness or fatigue of the wrist	**	9.28	1	0.87	0.27	2
Q15	Rate your soreness or fatigue in fingers	0.06	3.28	1	***	20.65	2
Q16	Rate your soreness or fatigue in neck or shoulder	*	4.77	1	0.33	2.20	2
Q17	How comfortable were you with your viewing position	0.20	1.62	1	*	7.66	2
Q18	How exciting was the experience	*	5.16	1	*	8.39	2
Q19	Overall, how satisfying or enjoyable was the experience you just had	0.97	0.0008	1	***	23.8	2
Q20	Rate suitability of the task to gameplay	0.85	0.03	1	***	24.25	2
Q21	Rate your sense of enjoyment	0.12	2.40	1	***	36.53	2
Q22	Rate your sense of accomplishment	0.41	0.65	1	***	16.68	2
Q23	Rate your soreness or fatigue in arms	0.30	1.07	1	0.81	0.40	2
Q24	Rate your precision/accuracy	0.81	0.05	1	0.12	4.22	2
Q25	Rate your control of the task	0.79	0.07	1	0.31	2.31	2
Q26	Rate your sense of challenge	0.75	0.10	1	0.09	4.70	2
Q27	Overall, how well do you feel you have been driving	0.38	0.76	1	0.17	3.46	2
Q28	Overall, how easily do you feel you have been driving	0.88	0.02	1	0.37	1.93	2

Eye strain was predicted by the display type (χ^2 (1) = 13.80, p =0.0002). A significant impact of the input device type on the sense of nausea was observed (χ^2 (2) = 9.07, p = 0.01). For the sense of dizziness, we saw display type significantly impacting it (χ^2 (1) = 4.26, p = 0.03). Finally, We observed that the sense of "fullness of head" was impacted by the display modality (χ^2 (1) = 4.66, p = 0.03).

5 DISCUSSION

This article explored how different combinations of steering input devices and display types for our driving simulator could impact participants' assessment of task load, simulator sickness, and usability. It was observed that both steering input devices lowered the general discomfort from SSQ, while the gamepad controller increased it. This observation agrees with the higher level of frustration from the usability data for the conventional controller. Wireless and stationary steering wheel devices also caused lower fatigue levels (form SSQ). The observations from the result section provide support for the claim that HMD and the realistic steering devices improve the sense of immersion and engagement with the driving experience.

Also, realistic steering devices helped participants to have a more satisfying driving experience and report less fatigue in their fingers. However, the monitor display was superior to the HMD in terms of reporting less fatigue in the neck and wrist and higher perceived picture quality and physical comfort. Relatively lower reported physical comfort and higher fatigue in the neck for the HMD scenarios were expected due to the additional weight of the headset. However, higher fatigue in the wrist for the HMD scenarios could be because, throughout the experiment, we observed that participants tend to match the physical position of the wireless steering device with its in-game position when using the HMD (that could cause more physical load on the wrists), while for the monitor-based scenarios they tend to hold the wireless steering device in a more comfortable position (usually on their feet) rather than trying to match it with the on-display position. Also, a higher immersion and engagement with an environment were reported for the HMD scenarios that made participants mimic and reproduce the real-life driving experience. Also, since the output resolution of the display and HMD were the same, higher perceived picture quality for the monitor scenarios could be related to the results from the simulator sickness data that participants reported a lower level of eye strain for the monitor scenarios, and therefore it impacted their perception of picture quality. In addition, according to (Vinnikov and Allison, 2014), which explored the impact of depth of field (DOF) for stereoscopic and non-stereoscopic displays on perceived image quality and viewing comfort, DOF rendering in HMD scenarios could be the reason for lower perceived im- age quality over monitor-based scenarios. Due to the no interaction effect of input and display modalities on usability questions, display, and input modalities aren't interdependent. Results indicated a strong interaction effect of input and display types on physical task load and self-evaluation of performance from the NASA task load questionnaire. Also, from the NASA task load, it was observed that the realistic in- put devices (i.e., wireless and stationary wheels) lowered the level of reported frustration compared to the gamepad controllers. Although the stationary steering wheel caused the lowest amount of frustration regardless of the display type, it decreased the self-evaluated performance when paired with the monitor display. This observation implies that the realistic in-put device results in the best performance assessment paired with a more immersive display method. In line with these results, (McMahan et al., 2012) also showed that the compound effect of input and display fidelity, when both are high or low fidelity, improves the performance in their game scenario discussed in the related works section. Steering input devices and large display scenarios lowered the self-reported ratings for the headache symptom relative to other conditions. Higher levels of eye strain (from SSQ) have been recorded for the HMD in comparison to the monitor display scenarios. Interestingly, regarding the nausea symptom (from SSQ), wireless stationary steering input devices recorded lower levels, regardless of the display setup. This is significant because no interaction effect has been shown on nausea. Also, HMD-based scenarios indicated a higher degree of reported dizziness than monitor-based ones. Finally, from the SSQ, similar to the dizziness symptom, a higher degree of fullness of the head has been shown for the monitor display scenarios. These results indicate that when a realistic controlling scheme is paired with an immersive display type, symptoms associated with simulator sickness tend to decrease. However, although in general monitor-based scenarios caused fewer simulator sickness symptoms, when paired with realistic input devices caused more symptoms in comparison to when paired with a controller. Also, according to the results, lower discomfort for the monitor display scenarios from the SSQ data confirms the observation from the usability questionnaire. In addition, the usage of realistic input devices (stationary and wireless steering devices) lowered the discomfort, which could be because the control scheme for those devices was intuitive to the driving task (higher suitability of task to gameplay for the steering wheels from the usability results) in comparison to the scenarios with a gamepad controller. Despite these observations, results from NASA TLX questionnaire indicated that a stationary steering device, when paired with the monitor display, causes a higher level of physical task load. This observation suggests that although the more intuitive control scheme causes lower physical discomfort when paired with immersive stimulus presentation, it also mitigates the physical task load overhead of realistic interactions and force feedback.

6 CONCLUSION

This study focused on evaluating different types of steering devices and display methods in a driving simulator in relation to participants' subjective assessment of the driving experience. Six stimulus presentation and interaction blocks were designed to comprise all possible pairs of two steering devices and controllers and two display methods. The results indicate that in terms of immersion, sense of presence, sense of agency, comfort, and achievement, two steering wheels (wireless and stationary), especially when paired with VR headset, are superior to conventional VR and non-VR controllers. Further analysis of gaze-steering correlation, distribution of fixations across the Area of Interest (AOI)s, and the relationship between subjective assessment of task load and calculated steering effort, based on made trajectories, is in perspective. One shortcoming of the current works was the lack of the ability of natural steering (actual rotation) for the conventional controllers. Also, due to the increasing number of variables, we did not account for participants' positional and rotational information in the blocks with large displays. Finally, this work had a limited number of road types and driving scenarios. Nonetheless, more studies are needed to address the exact variables associated with steering devices and displays related to observed impacts on subjective assessments. Possible improvements for controller-based scenarios should be examined. Due to the variability of optical flow in different scenes, when driving, further investigation into the relationship between changes in optical flow and its impact on gaze-steering correlation is essential. Then, we can address how changes in the visual information (in urban vs. rural scenes) that alter perceived motion and are associated with simultaneous steering actions could constitute the levels of bodily discomfort and task load (physical, cognitive, temporal).

REFERENCES

Accot, J. and Zhai, S. (1999). Performance evaluation of input devices in trajectory-based tasks: an application of the steering law. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems*, pages 466–472.

Brey, P. and Søraker, J. H. (2009). Philosophy of computing and information technology. In *Philosophy of technology and engineering sciences*, pages 1341–1407. Elsevier.

Chang, K.-H. (2016). *e-Design: computer-aided engineering design*. Academic Press.

Corporation, H. (2018). *VIVE Pro HMD User guide*.

Cruz-Neira, C., Sandin, D. J., DeFanti, T. A., Kenyon, R. V., and Hart, J. C. (1992). The cave: audio visual experience automatic virtual environment. *Communications of the ACM*, 35(6):64–73.

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of experimental psychology*, 47(6):381.

Haas, J. K. (2014). A history of the unity game engine.

Harris, D., Wilson, M., and Vine, S. (2020). Development and validation of a simulation workload measure: the simulation task load index (sim-tlx). *Virtual Reality*, 24(4):557–566.

Hart, S. G. and Staveland, L. E. (1988). Development of nasa-tlx (task load index): Results of empirical and theoretical research. In *Advances in psychology*, volume 52, pages 139–183. Elsevier.

Hedegaard, M., Støttrup, N., Sørensen, F. F., Langer, T. H., and Samani, A. (2019). Evaluation of five steering input devices in terms of muscle activity, upper body kinematics and steering performance during heavy machine simulator driving. *International Journal of Industrial Ergonomics*, 72:137–145.

Hyperkin (2019). *S Wheel Wireless Racing Controller User Manual*.

Kountouriotis, G. K., Wilkie, R. M., Gardner, P. H., and Merat, N. (2015). Looking and thinking when driv- ing: The impact of gaze and cognitive load on steer- ing. *Transportation research part F: traffic psychol- ogy and behaviour*, 34:108–121.

Kuznetsova, A., Brockhoff, P. B., and Christensen, R. H. (2017). lmertest package: tests in linear mixed effects models. *Journal of statistical software*, 82:1–26.

Logitech (2015). *Logitech G920 Driving Force Racing Wheel User Guide*.

Luxton, D. D., June, J. D., Sano, A., and Bickmore, T. (2016). Intelligent mobile, wearable, and ambient technologies for behavioral health care. In *Artifi- cial intelligence in behavioral and mental health care*, pages 137–162. Elsevier.

Manufacture, N. Windridge city Unity Asset.

McMahan, R. P., Bowman, D. A., Zielinski, D. J., and Brady, R. B. (2012). Evaluating display fidelity and interaction fidelity in a virtual reality game. *IEEE transactions on visualization and computer graphics*, 18(4):626–633.

Microsoft. *Xbox One Wireless Controller*.

Sportillo, D., Paljic, A., Boukhris, M., Fuchs, P., Ojeda, L., and Roussarie, V. (2017). An immersive virtual reality system for semi-autonomous driving simulation: a comparison between realistic and 6-dof controller-based interaction. In *Proceedings of the 9th International Conference on Computer and Automation Engineering*, pages 6–10.

van Leeuwen, P. M., Gómez i Subils, C., Ramon Jimenez, A., Happee, R., and de Winter, J. C. (2015a). Effects of visual fidelity on curve negotiation, gaze behaviour and simulator discomfort. *Ergonomics*, 58(8):1347– 1364.

van Leeuwen, P. M., Happee, R., and de Winter, J. C. (2015b). Changes of driving performance and gaze behavior of novice drivers during a 30-min simulator-based training. *Procedia Manufacturing*, 3:3325– 3332.

Vinnikov, M. and Allison, R. S. (2014). Gaze-contingent depth of field in realistic scenes: The user experience. In *Proceedings of the symposium on eye tracking research and applications*, pages 119–126.