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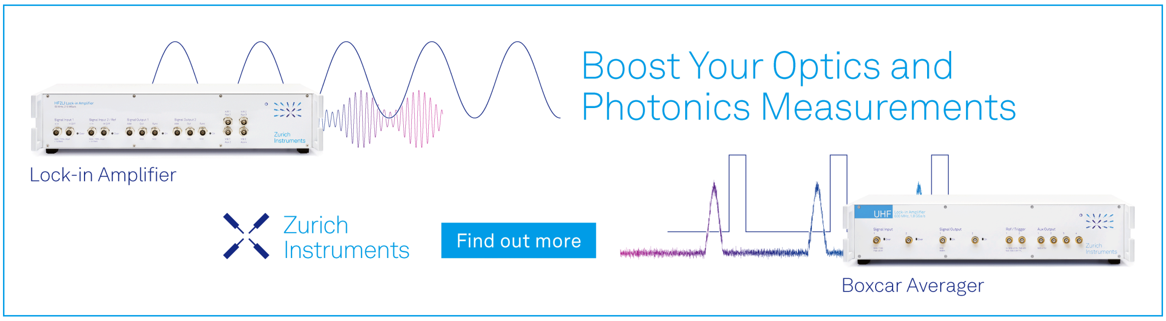

Effects of Ride Comfort on Different Non-Driving Related Activities in Fully Automated Driving Experience

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Abstract. A fully automated vehicle (AV) is projected to free users from driving activities. However, motion sickness (MS) is expected to be experienced by the users when engaging in Non-Driving Activities (NDRAs) such as reading, and watching a video because they will be exposed to low-frequency movement that contributes to the development of motion sickness. This study analyzed the difference in users' ride comfort when traveling in an AV in a real-road situation. The Wizard of Oz method was implemented for the participants to experience fully automated driving. The study was divided into three stages: pre-, during, and post-driven, to measure the user's comfort, safety, likeness, and motion sickness level through self-report questionnaires. Three conditions of NDRA consisting of baseline (doing nothing), reading, and watching a video were tested among the young participants (18 to 28 years old, Mean = 21.4, Standard Deviation = 2.84). Statistical analysis showed a statistically significant difference between the three different NDRAs. Reading imposed the highest experienced MS followed by watching a video and doing nothing. Understanding ride comfort in AV riding is vital in designing an AV that makes the passenger enjoy the ride without any discomfort feeling (motion sickness), especially when engaging in any NDRAs.

INTRODUCTION

Autonomous driving has the possibility to reduce traffic accidents since an Automated Vehicle (AV) is equipped with multiple sensors such as LiDAR (Light Detection and Ranging), sensor vision cameras, and radar sensors (Yeong et al., 2021). An important part of safe navigation is detecting and tracking agents in the vehicle's surroundings**.** When the vehicle is moving, the vehicle always receives the signal from the sensors to maintain a safe condition between other road users. "Autonomous technology" refers to technology that has the capability to drive a vehicle without active physical control or monitoring by a human operator (Policy, 2018).

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A technology that executes a function that was previously performed by humans has been defined as an automation (Parasuraman & Riley, 1997). Whether the automation is partial or full, it gives a huge advantage to people in meeting task goals. The Society of Automotive Engineers has described the level of vehicle autonomy into six: the human driver needs to oversee the driving environment (Levels 0–2), and an automated driving system oversees the driving environment (levels 3–5) (International, 2018; Zmud et al., 2017). The role of the human driver will change to the passenger since the level of automation increases to level 3–5 of automation. The human driver no longer needs to do driving tasks such as controlling the wheel or gas and brake pedal since the AV is taking over the driving tasks. The AV users can perform and engage in the activities they want inside the AV during travelling such as watching videos or resting. Depending on the type of journey, AV users can engage in various non-driving-related activities (Jorlöv et al., 2017). Wadud and Huda (Wadud & Huda, 2020) found that different types of journeys affect AV users to engage in different activities.

However, for an AV user to engage the non-driving related activity during the journey, s/he is predicted to experience motion sickness symptom (Karjanto et al., 2021; Probst et al., 1982) based on theories such as sensory conflict theory (Reason & Brand, 1975) and postural instability theory (Riccio & Stoffregen, 1991). A study was done by Kot et al. (Kot, 2021) to understand the effects of vibrations on motion sickness on the participants when they were being driven by an AV. The results found that there was an increase in motion sickness levels when they were exposed to longer driving and performing reading as a non-driving related activity. Another study found that the AV users did not feel any motion sickness when they were driven by an AV when doing nothing as a non-driving related activity was performed throughout the automated rides (Norzam et al., 2022). Engaging in different non-driving related activity generates a different level of motion sickness experienced by AV users.

In this study, the participants were exposed to three different conditions (doing nothing, reading texts, and watching video) in order to explore their respond in terms of riding comfort and motion sickness assessment when being driven by a Defensive AV. It was expected that the participants feel comfort, safe and experience no motion sickness when they were not performing any non-driving related activity and experience motion sickness when they are performing non-driving related activities. The results also expected that the participants experience higher motion sickness in reading compared to watching video.

METHODOLOGY

Participants

The participants were selected from the local students at Universiti Tun Hussein Onn Malaysia (Pagoh Campus) which consists of 13 participants (Male = 6, Female = 7) aged between 18 - 28 (Mean = 21.38, SD = 2.84) using a same designated route. Out of 13 participants, five were selected from the works of Norzam et al. (Norzam et al., 2022) who possess Motion Sickness Susceptibility Questionnaire (MSSQ) scores above 50% and used as a baseline for analysis. MSSQ was developed by Golding et al. (Golding, 1998, 2006) to study people's susceptibility to motion sickness. The MSSQ score is based on the 100% scale, with higher numbers indicating more sensitivity to motion sickness. The participants with mild (50% - 74%) and severe (75% - 100%) susceptibility were selected in this study based on the MSSQ's scores (Mean = 81.54%, SD = 18.71%). In Norzam et al. (Norzam et al., 2022) works, the non-driving related activity engaged by participants were doing nothing. In this study, the remaining participants were engaged two different non-driving related activities (reading and watching video) on different experiment session by using within-subject design experiment. The experiments executed at least one day apart from the first experiment session to make sure that no experiment effects in previous session.

AV Ride Simulation

The experiment was conducted through a Wizard of Oz approach that was invented by Baltodano et al. (Baltodano et al., 2015) work. Two experimenters played a big role in this study: the Driving Wizard and the Interactive Wizard. The Driving Wizard's role was to drive the Testing Vehicle as if an AV is driving the vehicle. The Driving Wizard ran through numerous hours of training to make sure that the acceleration, deceleration, and cornering produced were within the range of a Defensive AV driving style (Karjanto et al., 2018, 2021; Nidzamuddin Md Yusof et al., 2016). While the Interactive Wizard's role was to act as a third person between the participant and Driving Wizard. Also, the Interactive Wizard recorded the data gained from the participants. The seating position of Driving Wizard, Interactive Wizard, and participants is shown in Fig. 1.

Testing Vehicle

The Testing Vehicle was equipped with an accelerometer and data acquisition system (DAQ). The National Instrument cRIO-9030 DAQ and an ADXL335 3-axis accelerometer were used in this study. The accelerometer was placed at the middle console, approximately at the vehicle's center of gravity (see Fig. 2). The accelerometers were connected to the DAQ sampled at 250 Hz.

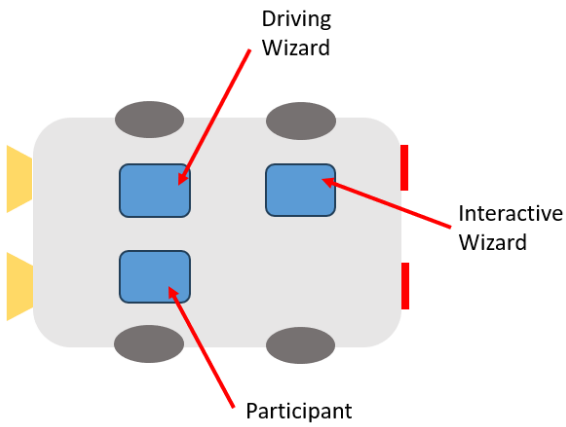

FIGURE 1. The seating position of the Driving Wizard, Interactive Wizard, and participant

A device called Automatic Acceleration and Data Controller (AUTOAccD) was implemented to help the designated driver in driving according to the defined acceleration condition (Karjanto et al., 2017, 2018). The Driving Wizard can calibrate the speed and braking by adjusting the gas and brake pedal during lateral acceleration by viewing the live acceleration data from AUTOAccD (see Fig. 2). During cornering, the induced force made by the Driving Wizard displayed on the screen of AUTOAccD. The Driving Wizard must make sure that the force is in the range of defensive (green) in each cornering. If the acceleration is less or more, the Driving Wizard can adjust the acceleration to get the desired force.

FIGURE 2. AUTOAccD at Defensive AV driving style range when cornering (green)

The experimental device used in this experiment the participants to engage non-driving related activity was iPad 10 pro with dimension of 250.6 x 174.1 x 6.1 mm (9.87 x 6.85 x 0.24 inch). The device was fixed at 79 cm from the ground and 40 cm from the front windscreen using a Delkin Devices Fat Gecko Triple Mount (see Fig. 3). The separator was used to able the participants experiencing a passenger in a fully AV by blocking their view from Driving Wizard.

FIGURE 3. Tablet position

A look-alike LiDAR was 3D-printed and placed on the Testing Vehicle's roof to increase the saliency of simulating an AV riding experience (see Fig. 4).

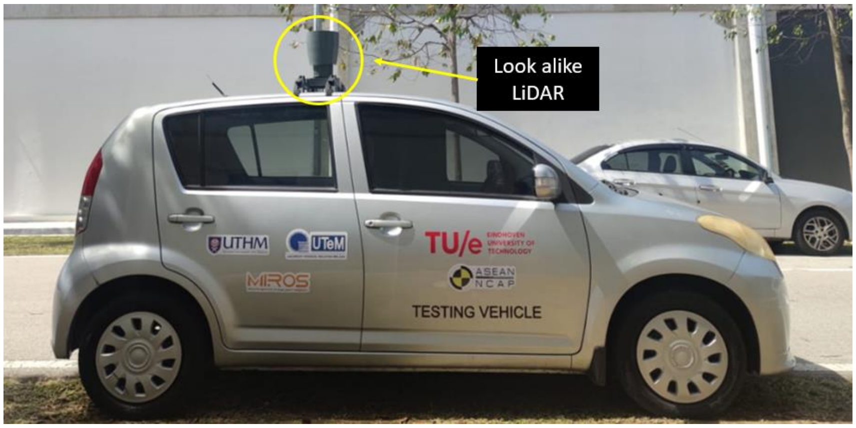

FIGURE 4. Testing Vehicle

Questionnaire

Test Ride Rating - This study applied four individual rating scales, labelled as R1 (Driving Style Refinement), R2 (Comfort), R3 (Pleasantness), and R4 (Safety Rating), to express participants' judgement on the simulated test rides. All of the items were five-point Likert scale, with R1: 1 represented to "the force is much too low" and 5 represented to "the force is much too high" R2: 1 represented to "very comfortable" and 5 represented to "very uncomfortable," R3: 1 represented to "very pleasant" and 5 represented to "very unpleasant," and R4: 1 represented to "very safe" and 5 represented to "very dangerous," (Nidzamuddin Md Yusof et al., 2016).

Motion Sickness Assessment Questionnaire (MSAQ) - It consists of 16 questions on a 9-point scale (1= not at all, 9 = severely) that was developed by Gianaros et al. (Gianaros et al., 2001). The 16 questions can be divided into four components: gastrointestinal, central, peripheral, and sopite-related symptoms of motion sickness. Therefore, MSAQ can be displayed as a single cumulative score and as four subscores for each configuration.

Misery Scale (MISC) - It consists of 11-point scale that was developed by Wertheim et al. (Wertheim et al., 2001). It covers symptoms such as discomfort, dizziness, headache, stomach-ache, sweating, blurred vision, yawning, burping tiredness, salivation, nausea, and vomiting. In this study the grading method from Bos et al. (Bos et al., 2005) was used for the participants to express their experienced motion sickness.

Procedure

The experiments were divided into three stages: Stage 1 (pre-driven), Stage 2 (driven phase), and Stage 3 (post-driven). The purpose of Stage 1 and Stage 3 was to find the level of experienced motion sickness before and after the test ride.

In Stage 1, the Interactive Wizard explained the process of the experiment and informed consent to the participants upon their arrival. Participants were allowed to stop the study at any time if they could not continue the experiment as motion sickness was expected to occur. Before beginning Stage 2, the participants answered pre-experiment questionnaire (pre-MSAQ). Then, the participants were guided by Interactive Wizard to the Testing Vehicle. The vehicle was driven by Driving Wizard following a defensive AV driving style range of speed and acceleration following the designated route where all the traffics law applied (Stage 2). During Stage 2, in each 2-minutes interval, the Interactive Wizard asked about what the participants felt at the moment based on the MISC. The participants orally stated by mentioning the score and recorded by Interactive Wizard. During the whole Stage 2, the participants continuously performed non-driving related activities given by Interactive Wizard.

After the driven phase, the participants answered the post-experiment questionnaires (post-MSAQ and Test Ride Rating) based on their experience throughout the simulated test ride (Stage 3). Participants completed the questionnaire straightway after exiting the Testing Vehicle to minimize washout effects (Louis et al., 1984). Finally, the participants were debriefed and compensated RM 30 for their cooperation in the experiment. The experiment was repeated for second non-driving related activity on a different day. The order of non-driving related activity was randomized to prevent the participants from learning the experiment's purpose.

RESULTS AND DISCUSSION

Test Ride Analysis

Mann-Whitney U Test was performed on two type of non-driving related activity to see if there were any statistical differences in three different directions; longitudinal acceleration (Long. Acc.), longitudinal deceleration (Long. Dec.), and lateral acceleration (Lat. Acc.). The data were obtained from the questionnaires answered by participants, and it showed that there were no statistical differences between the participants ($p > 0.05$) of the test ride simulation (see Table 1 and Table 2).

In rating of Driving Style Refinement, the participants stated that they were satisfied to the induced motion generated by Testing Vehicle in three directions for both analyses of doing nothing and reading and doing nothing and watching video. They felt so because the 'Defensive' style of driving was perceived as more trustworthy (Basu et al., 2017; Hecker et al., 2019; Pyre, 2021) so the chances of an accident to occur are low. They were comfortably engaging in non-driving related activity throughout the journey. However, when participants doing nothing as the non-driving related activity, they stated that a slightly less force is required during cornering of the simulated test ride. They experienced the extra induced force because they were more aware of the surrounding (environment and car movement) when they were doing nothing in a moving vehicle. But, when participants were reading and watching a video, they stated that they satisfied to the induced force as they were more focus on engaging the non-driving related activity.

The median scores of the participants when reading and watching video were slightly higher (2.00) compared to when they were doing nothing (1.00) in terms of comfort, pleasantness and safety. When passengers do any activities inside a moving vehicle, they tend to become less aware of the surroundings and their mental demand could be increased (Dogan et al., 2017; Winter et al., 2014; Yoon & Ji, 2019). The participants felt less comfort, pleasant and safe as they were barely aware of the environment surrounding and more focus on the performing non-driving related activity. When engaging in a non-driving related activity, the role of the passenger will switch from driver (Bengler et al., 2020) and they would find it harder to predict the acceleration, deceleration and cornering of the vehicle. Thus, an uncomfortable feeling might experience by the passenger. However, in general, they still felt comfort, pleasant and safe when performing reading and watching video when being driven in a defensive AV driving style.

TABLE 1. Rating analysis between doing nothing and reading at three different direction

Rating	Participant (Median)	Direction	*Mann-Whitney U Test*
Driving Style Refinement	Doing Nothing (3.00) Reading (3.00)	Long. Acc.	$U = 18, z = -0.397, p = 0.833$
	Doing Nothing (3.00) Reading (3.00)	Long. Dec.	$U = 23, z = 0.503, p = 0.724$
	Doing Nothing (2.00) Reading (3.00)	Lat. Acc.	$U = 29, z = 1.456, p = 0.222$
Comfort	Doing Nothing (1.00) Reading (2.00)	Long. Acc.	$U = 24, z = 0.629, p = 0.622$
	Doing Nothing (2.00) Reading (2.00)	Long. Dec.	$U = 21, z = 0.156, p = 1.000$
	Doing Nothing (1.00) Reading (2.00)	Lat. Acc.	$U = 22.5, z = 0.384, p = 0.724$
Pleasantness	Doing Nothing (2.00) Reading (2.00)	Long. Acc.	$U = 14.5, z = -0.882, p = 0.435$
	Doing Nothing (2.00) Reading (2.00)	Long. Dec.	$U = 13.5, z = -1.023, p = 0.354$
	Doing Nothing (2.00) Reading (2.00)	Lat. Acc.	$U = 16, z = -0.624, p = 0.622$
Safety	Doing Nothing (1.00) Reading (2.00)	Long. Acc.	$U = 22.5, z = -0.397, p = 0.724$
	Doing Nothing (1.00) Reading (2.00)	Long. Dec.	$U = 26.5, z = 1.053, p = 0.354$
	Doing Nothing (2.00) Reading (2.00)	Lat. Acc.	$U = 19, z = -0.159, p = 0.943$

TABLE 2. Rating analysis between doing nothing and watching video at three different direction

Rating	Participant (Median)	Direction	*Mann-Whitney U Test*
Driving Style Refinement	Doing Nothing (3.00) Watching Video (3.00)	Long. Acc.	$U = 14, z = -1.020, p = 0.435$
	Doing Nothing (3.00) Watching Video (2.50)	Long. Dec.	$U = 16, z = -0.624, p = 0.622$
	Doing Nothing (2.00) Watching Video (2.50)	Lat. Acc.	$U = 22.5, z = 0.398, p = 0.724$
Comfort	Doing Nothing (1.00) Watching Video (2.00)	Long. Acc.	$U = 25, z = 0.796, p = 0.524$
	Doing Nothing (2.00) Watching Video (2.00)	Long. Dec.	$U = 19.5, z = -0.080, p = 0.943$
	Doing Nothing (1.00) Watching Video (2.00)	Lat. Acc.	$U = 23.5, z = 0.538, p = 0.622$
Pleasantness	Doing Nothing (2.00) Watching Video (2.00)	Long. Acc.	$U = 14.5, z = -0.846, p = 0.435$
	Doing Nothing (2.00) Watching Video (2.00)	Long. Dec.	$U = 13.5, z = -1.023, p = 0.354$
	Doing Nothing (2.00) Watching Video (2.00)	Lat. Acc.	$U = 16, z = -0.670, p = 0.622$
Safety	Doing Nothing (1.00) Watching Video (2.00)	Long. Acc.	$U = 22.5, z = 0.397, p = 0.724$

	Doing Nothing (1.00) / Watching Video (2.00)	Long. Dec.	*U = 26, z = 0.987, p = 0.435*
	Doing Nothing (2.00) / Watching Video (2.00)	Lat. Acc.	*U = 21, z = 0.162, p = 1.000*

Motion Sickness Assessment

Accessibility of Motion Sickness During Experiment

The value of Misery Scale was stated by participants at 2-minutes interval and a scatter plot for reading (x-marks) and watching a video (dot-marks) was plotted (see Fig. 5). As an overall, the scores increased (participants experienced increasing motion sickness) while the participants were exposed to the 10 minutes driving experience and expected to increase more if longer rides experience by participants (Norzam et al., 2022). The factors as discussed by Diels et al. (Diels & Bos, 2016) that makes motion sickness to occur such as the situation of passengers incapable to predict the future motion trajectory, the view of passengers when engaging non-driving related activity, and the seating positions and arrangements are most likely play a part in motion sickness to increase. Through the 10 minutes driven, the highest score recorded was 4; the participants felt fairly to the motion sickness symptoms (dizziness, warmth, headache, stomach awareness, or sweating). The scores was expected due to the designated route generates a mild motion sickness experienced by each participant based on the previous study (Norzam et al., 2022).

The average value of MISC scores for reading and watching a video were plotted on the line graph (see Fig. 5). The line of reading was slightly higher compared to watching a video at each 2-minutes interval. The participants that engage reading as a non-driving related activity does experience more motion sickness compare to watching a video (Schoettle & Sivak, 2009). More concentration is needed when reading (still image) compared to watching a video (moving image). Also, with the help of sound effect when watching a video, the participants were little distracted and more relaxed that made their concentration less.

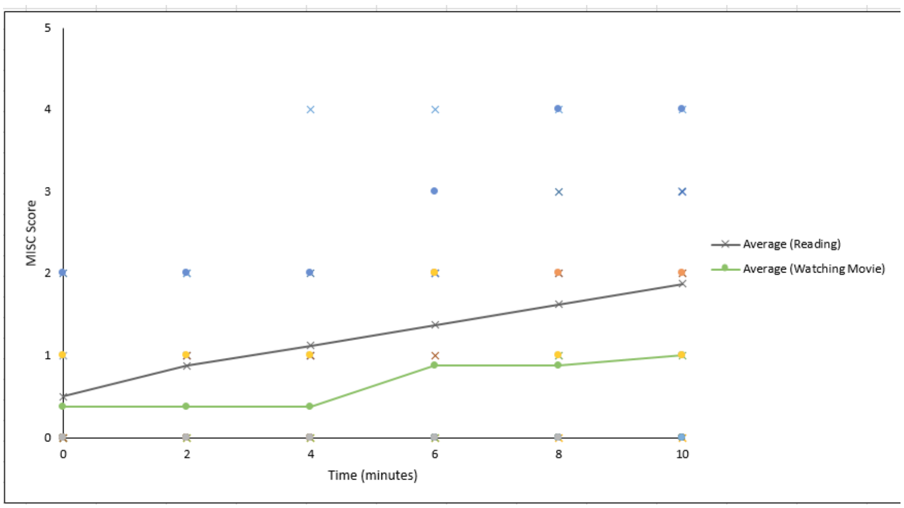

FIGURE 5. MISC Score and average score versus duration of throughout experiment during reading and watching a video for each participants

Wilcoxon signed-rank test was done to investigate whether there was any difference in reading and watching the video in 2-minutes interval throughout the experiment (see Table 3). As an overall, there was no statistical difference between the two non-driving related activities ($p > 0.05$). During the experiment session, both activities had the same factors (ability to anticipate the direction of movement and conflict between vestibular and visual input) that made the motion sickness worse as the participants engaged in non-driving related activity in a conventional vehicle (Sivak, Micheal, Schoettle, 2015). During engaging in a non-driving related activity, participants have less awareness of the surroundings and experience motion sickness (N. Md Yusof et al., 2020) since they do not know what is going on in the car’s condition (movement). According to the sensory conflict theory which was first introduced by Reason and Brand (Reason & Brand, 1975), motion sickness developed due to the conflicting human senses (vestibular, somatosensory, and visual systems) are incorporated together in developing the awareness of motion presented. During engaging in a non-driving related activity (for example, reading or watching a video), the eyes (visual systems) are static (do not sense the motion of movement), while the vestibular and somatosensory systems sense the motion of the vehicle.

TABLE 3. Results of MISC Score for the within-subject experiment in 2-minute interval for two types of non-driving related activity (NDRA)

Minutes	NDRA	Median	*Wilcoxon Signed-rank Test*
0	Reading	0.00	*z = -0.378, p = 0.705*
	Watching Video	0.00	
2	Reading	0.00	*z = -1.141, p = 0.157*
	Watching Video	-0.50	
4	Reading	0.00	*z = -1.141, p = 0.157*
	Watching Video	-0.50	
6	Reading	0.00	*z = -0.816, p = 0.414*
	Watching Video	0.00	
8	Reading	0.00	*z = -1.089, p = 0.276*
	Watching Video	-0.50	
10	Reading	0.50	*z = -1.236, p = 0.216*
	Watching Video	-0.50	

Evaluation On Motion Sickness Before and After Experiment Session

Wilcoxon Signed-rank Test were done on the pre- and post-MSAQ data to check if the test ride induces any motion sickness on three different type of the non-driving related activities (see Table 4). There was no statistically differences between all the pre- and post-MSAQ constructs when participants doing nothing and watching a video. However, in reading, the participants showed that there was a statistically difference in overall MSAQ especially in a central-related and sopite-related symptoms of motion sickness. Feeling faint-like, dizzy, and disoriented are the central-related symptoms of motion sickness while feeling drowsy (sleepy), tired, and uneasy are the sopite-related symptoms of motion sickness. Probst et al (Probst et al., 1982) stated that reading activity may generate an uncomfortable feeling when being driven in a moving vehicle. A study with 31 participants in Japan done by Isu et al. (Isu et al., 2014), they discovered that reading induced 3.5 times more motion sickness than not performing any non-driving related activity. Also, another study found that reading gave a higher motion sickness compared to watching a video (Kato & Kitazaki, 2006, 2008). Reading and watching a video generate 3.3 times and 2.9 times respectively more than not performing any non-driving related activity.

From the statistical analysis obtained in Table 4, most of the z-value of MSAQ constructs are positive values. It indicates that the motion sickness of the participants when they were engaging non-driving related activity increased after they were driven. But the symptoms of peripheral-related (sweaty or feeling hot/warm) for doing nothing and watching video showed that the motion sickness of the participants decreased. This was due to the hot surrounding temperature of the participants before they participated the experiment session. During the experiment session, participants were exposed to the air-conditioning inside the Testing Vehicle.

For the most part, median scores of watching a video were slightly higher compared to doing nothing. Watching a video also needs focus and effort to perform the activity although it was not as high as reading. From Table 4, the most activity that generate motion sickness experienced by the participants throughout the 10 minutes’ journey is reading followed by watching video and doing nothing.

TABLE 4. Results of the pre- and post-MSAQ scores for the overall MSAQ (O) and its constructs (gastrointestinal-related (G), central-related (C), peripheral-related (P), and sopite-related (S)) for three different non-driving related activity (NDRA)

Type of NDRA	MSAQ	Situation	Median (%)	*Wilcoxon Signed-rank Test*
Doing Nothing	G	Pre Post	11.11 11.11	*z = 0.447, p = 0.655*
	C	Pre Post	11.11 11.11	*z = 1.089, p = 0.276*
	P	Pre Post	11.11 11.11	*z = -1.000, p = 0.317*
	S	Pre Post	11.11 19.44	*z = 0.736, p = 0.461*
	O	Pre Post	11.81 15.28	*z = 0.552, p = 0.581*
Reading	G	Pre Post	11.11 12.50	*z = 1.461, p = 0.144*
	C	Pre Post	11.11 21.11	*z = 2.023, p = 0.043**
	P	Pre Post	11.11 12.96	*z = 0.542, p = 0.588*
	S	Pre Post	11.11 19.44	*z = 2.207, p = 0.027**
	O	Pre Post	11.11 21.18	*z = 2.197, p = 0.028**
Watching Video	G	Pre Post	11.11 11.11	*z = 0.000, p = 1.000*
	C	Pre Post	11.11 14.44	*z = 1.604, p = 0.109*
	P	Pre Post	14.81 12.96	*z = -0.738, p = 0.461*
	S	Pre Post	12.50 19.44	*z = 1.577, p = 0.115*
	O	Pre Post	12.85 14.58	*z = 1.703, p = 0.089*

** Indicates that there was a statistically difference, (p<0.05)*

CONCLUSION

Different non-driving related activity (doing nothing, reading, and watching a video) showed different results through statistical analyses. As an overall, the participants were satisfied towards the induced motion of simulated AV driven by Driving Wizard in longitudinal acceleration and deceleration. However, in lateral acceleration, the induced forced can be improved in future work of this study to satisfy the passenger when engaging non-driving related activity. In terms of comfort, pleasant, and safety, they gave a positive result toward the simulated AV. Still, during reading condition, participants developed uncomfortable feeling in sopite-related construct over pre- and post-MSAQ. From MSAQ, reading imposed the highest experienced motion sickness followed by watching a video and doing nothing. Furthermore, participants stated that they experienced more motion sickness in reading compared to watching video through MISC. The range of acceleration and deceleration in longitudinal and lateral direction should be further study when engaging non-driving related activity especially in reading activity to minimize the motion sickness felt by the AV users.

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