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MOTION SICKNESS IN A FULLY AUTOMATED VEHICLE: HOW DOES PASSENGER FEEL WHEN ENGAGING IN NON-DRIVING RELATED ACTIVITIES

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Abstract

Non-driving related activities (NDRA) such as reading and watching videos are some of the everyday activities to be done by the passenger when they are traveling in a vehicle. The passengers are expected to experience uncomfortable feelings such as motion sickness (MS) from mild MS and, worst case, vomit when engaging NDRA. Twenty-two participants (7 males and 15 females), aged between 20 and 28 years old (Mean = 23.05, SD = 2.51) that have Motion Sickness Susceptibility Questionnaire scores of more than 50% (Mean = 82.23, SD = 16.5) were selected to join the experiment using a within-subject design. This study focused on how the passengers felt when they engaged NDRA throughout the experiment session (before, during, and after the driven phase) when driving by a Defensive Automated Vehicle driving style. The results found that the participants experienced MS during and after the driven phase in both NDRAs. Also, the results found that reading activity induced more MS than watching a video.

Keywords: Automated vehicle, Motion sickness, Non-Driving related activity, Ride comfort.

1. Introduction

Someday, humans will no longer need to drive vehicles since automated vehicles (AV) will take over human driving. The driving tasks change and adapt more toward the driving systems due to the increasing technological progression and integration of the systems [1]. The Automated Driving Roadmap, created by the European Road Transport Research Advisory Council, defines the various automation systems and estimates the potential deployment date. It was predicted that by 2026-2030, an AV would be fully ready to be driven on the road [2].

The Society of Automotive Engineering (SAE) classified six levels of automation. From Level 0 to Level 2, the human driver handles some or all dynamic driving activities. While in Level 3 to Level 5, the human driver no longer needs to perform dynamic driving activities since the activities shift to automated driving systems [3]. In Level 3 of automation, the system will send a timely request to the fallback-ready driver to intervene in the event of a dynamic driving activity failure. While in Level 4 and Level 5 of automation, the system controls the dynamic driving activities fallback.

When certain levels of automation (SAE level 3-5) are reached, the AV system can drive itself either with or without the help of human inputs, depending on each level. Hence, humans are slowly becoming passengers from drivers since AV is gradually taking over driving from humans. Therefore, humans can do any non-driving related activities they prefer inside a moving vehicle that AV drives, such as eating and drinking, watching movies, reading books, or playing games.

Doing non-driving related activities (NDRA) inside a moving vehicle is expected to develop an uncomfortable feeling known as motion sickness. Diels et al. [4] stated that carsickness would occur when a human does any activities inside a moving vehicle based on the sensory conflict theory of motion sickness. The theory states that motion sickness occurs when the visual system is not synchronized with the vestibular and somatosensory systems.

Based on the previous study done by Karjanto et al. [5], they assessed the motion sickness of participants before and after the driving (test ride) session when participants engaged in NDRA (reading). Another study was done by Salter et al. [6] to assess motion sickness while engaging in NDRA (office tasks) through a driving simulator. They analysed the motion sickness data obtained after the drive.

An AV should have a specific driving style that would make the passenger not feel any motion sickness when they do any NDRAs inside a moving vehicle. The driving style should include all the tri-axial accelerations: longitudinal, vertical, and lateral. This study is an extension study from Norzam et al. [7]Click or tap here to enter text. that involved NDRAs (reading and watching a video) to be performed by participants while being driven by the Defensive AV driving style on an actual road situation where all the traffic laws applied. This study also focused on how the Malaysians felt (before, during, and after the driven phase) when they were being driven.

2. Methods

2.1. Instrumented vehicle

The study used a customized subcompact car, Perodua Myvi, from University Tun Hussein Onn Malaysia (UTHM) laboratory named Instrumented Vehicle. The Instrumented Vehicle was completed with multiple equipment to take and record the measurements, such as accelerometers, gyro meters, GPS, microcontroller, TFT LCD, and micro-SD. A tri-axial accelerometer called ADXL335 was mounted in the vehicle's centre to evaluate acceleration in longitudinal, lateral, and vertical directions. Another ADXL335 was used to take the measurements of head movements. The accelerometer was sewed to the headband and to be worn by the participants.

All data should be timestamped consistently, with automatic data logging for further analysis because it can execute re-configurable field-programmable gate array (FPGA) applications on a real-time processor; the National Instrument compact RIO-9030 (NI cRIO 9030) was used in this investigation.

A unique device invented by Karjanto and Yusof et al. [8] called Automatic Acceleration and Data Controller (AUTOAccD) was placed on the right side of the front windscreen near the driver's seat. Onboard diagnostic (OBD) adapters and accelerometers were among the electronic parts of the AUTOAccD. The OBD adapter was coupled to an OBD connector in the vehicle with a 3.2” LCD. This study's electrocardiogram (ECG) sensor is AD8232 [9].

A tablet (250.6 × 174.1 × 6.1 mm) was also used for the NDRAs. The device was fixed 79 cm from the ground and 40 cm from the front windscreen using a Delkin Devices Fat Gecko Triple Mount. The device's position was placed at face level (head-up display) to reduce the likelihood of motion sickness to occur [10]. A separator is used to enable the participants to experience a passenger in a full AV by blocking their view from the Driving Wizard (see Fig. 1).

2.2. Wizard of Oz

A Wizard of Oz approach by Baltodano et al. [11] was used in this study to simulate AV riding to enable the participants to experience being driven by an AV. Wizard of Oz has two prominent experimenters: the Driving Wizard and the Interactive Wizard.

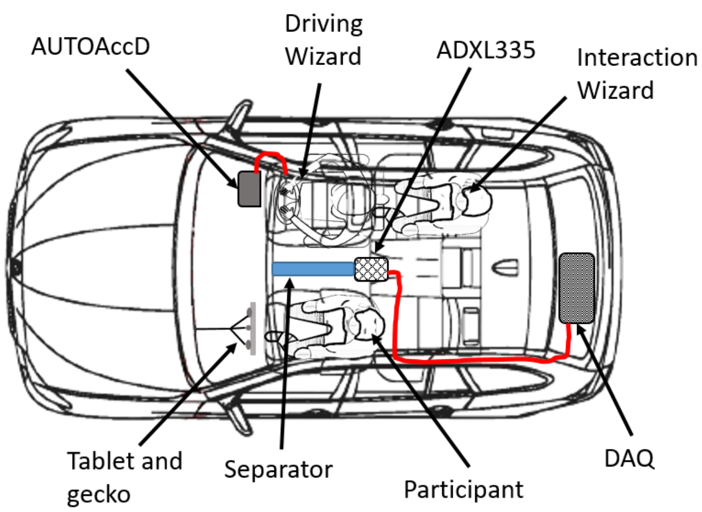

Fig. 1. The position of the driving wizard, interaction wizard, and participant [7].

The Defensive AV driving style (DS) was implemented by the Driving Wizard to simulate riding on a real-road situation with the help of unique equipment (AUTOAccD) [8] as a guide for the Driving Wizard to drive like a Defensive AV. From previous studies, participants preferred to be conducted in a Defensive AV DS regardless of their DS [12-14]. Therefore, the driving speed was set at 1.37 to 2.45 m/s^2, the lateral force produced when turning or cornering was about 1.47 to 4.12 m/s^2, and the vertical force caused when across the speed hump was 0.00 to 1.57 m/s^2.

The Interactive Wizard acts as a person who interacts with participants during the whole experiment. If there was any request by participants, the Interactive Wizard should fulfil it. During the investigation, the Interactive Wizard was seated at the back of the Driving Wizard, and the participants were sitting beside the Driving Wizard (see Fig. 1).

2.3. Measurements

2.3.1. Vehicle

Motion Sickness Dose Value. An approach for determining the dose of motion sickness from acceleration is prescribed by the International Organization for Standardization (ISO) [15].

2.3.2. Participants

Test Ride Rating. This study applied four individual self-rating scales, labelled R1 (Driving Style Refinement), R2 (Comfort), R3 (Pleasantness), and R4 (Safety Rating), to express participants' judgment on the simulated test rides. The self-rating questionnaire was a five-point Likert scale, with R1: 1 representing "the force is much too low" and 5 representing "the force is much too high," R2: 1 representing "very comfortable" and 5 representing "very uncomfortable," R3: 1 representing "very pleasant" and 5 representing "very unpleasant," and R4: 1 representing "very safe" and 5 representing "very dangerous" [14].

Misery Scale. A unidirectional 11-point scale was developed by Wertheim et al. [16]. It covers discomfort, dizziness, headache, stomachache, sweating, blurred vision, yawning, burping, tiredness, salivation, nausea, and vomiting. Number 0 indicates no symptoms experienced, and the highest number, 10, indicates the worst symptom: vomiting. In this study, the grading method from Bos et al. [17]Click or tap here to enter text. was used for the participants to express their experienced motion sickness.

Motion Sickness Assessment Questionnaire. The questionnaire was a nine-point Likert scale that comprised 16 questions, with 1 representing "not at all" and 9 representing "severely," which was introduced by Gianaros et al. [18]. Gastrointestinal, central, peripheral, and sopite-related symptoms can all be included in the 16 questions. MSAQ can be divided into four sub-scores and a single total score for any structure.

Electrocardiogram. The severity of motion sickness of the participants can be assessed through the heart rates of participants. The capacity to acquire a continuous [19] recording of one's physiological condition and thus enable the experiment without stopping and gathering data are the grounds for using heart rate and HRV to quantify motion sickness.

Rating Scale Mental Effort. The questionnaire is a unidimensional instrument used to measure subjective mental workload [20]. The RSME consists of a line with nine anchor points marked with labels that each specify the level of effort along a 150 mm length. A value of 0 indicates ‘‘absolutely no effort,” and 150 indicates ‘‘maximum effort”.

Head movement. The effort made by participants when engaging NDRAs was measured by the movement of their heads.

2.4. Participants selection

The participants were selected from local students from University Tun Hussein Onn Malaysia (Pagoh Campus). Before the study was conducted, participants answered the Motion Sickness Susceptibility Questionnaire (MSSQ), and participants with mild and severe motion sickness (3rd and 4th quartile of MSSQ scores) were chosen to join the experiment (Mean = 82.23, SD = 16.5). The study involved 22 participants (7 males and 15 females), aged between 20 and 28 years old (Mean = 23.05, SD = 2.51), using a within-subject experimental design.

After the experiment, they were compensated MYR30 (~USD6) as a gift for their cooperation in the study. The sequence of the simulated test rides was reversed for each participant to counterbalance order effects and mitigate (2! = 2 orders).

2.5. Procedure

The experiment session was divided into three stages: before, during, and after the experiment, as illustrated in Fig. 2. The Interactive Wizard explained the whole experiment process as soon as the participant arrived. Then, the participants signed the consent form and answered the pre-experiment questionnaire.

The Interactive Wizard guided the participants about wearing ECGs on their bodies and headbands. Later, the participants were guided by Interactive Wizard to enter the Instrumented Vehicle and were asked to get their comfort by adjusting the seat and putting on the seat belt. Interactive Wizard told the participants they could abort the experiment if they could not handle the motion sickness.

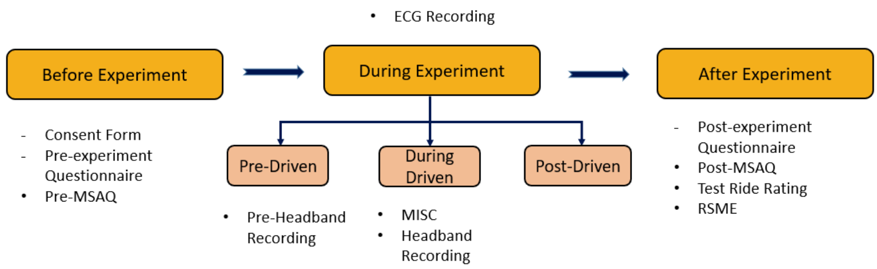

Fig. 2. The stages of the experiment study.

The second stage is divided into three phases: pre-driven, during driving simulation, and post-driven, where it took about 5, 10, and 5 minutes, respectively, to record the data from participants as recommended by Laborde et al. [21]. The pre-driven phase began when the Instrumented Vehicle was in a static position, and Interactive Wizard was instructed to engage NDRA during the second stage. After 5 minutes, the Driving Wizard drove the Instrumented Vehicle to the designated route.

During this phase, the Interactive Wizard asked how the participants felt about motion sickness every two minutes based on the Misery Scale. Then, the Instrumented Vehicle was static again for the post-driven phase. The participants can stop engaging the NDRA given after the post-driven phase once the Interactive Wizard gives an instruction.

Afterward, the participants answered post-experiment questionnaires guided by Interactive Wizard based on their experience during the experiment. Participants answered the questionnaire immediately after leaving the Instrumented Vehicle [22]. Finally, the ECG sensor was removed, followed by a debriefing and payment (MYR30) for their participation.

3. Results

3.1. Validation of driving simulation

3.1.1. Power spectral density

The acceleration of all 44 driving simulations in three-axes directions (longitudinal, lateral, and vertical) was plotted as a function of power spectral density (PSD) for both situations of NDRA (reading and watching a video) (see Fig. 3). The presiding frequency of the plotted PSD in three axes was below 0.2, 0.3, and 0.03 Hz, respectively.

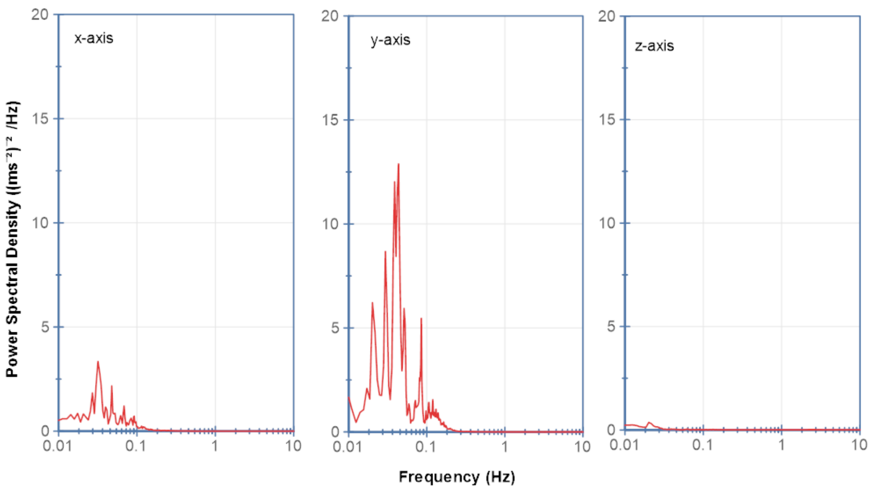

Fig. 3. Power Spectrum Densities (PSDs) of acceleration in three axes.

3.1.2. Test ride analysis

The Wilcoxon Signed-rank Test (WSRT) was performed to determine the difference in participants' experience when reading and watching a video in longitudinal acceleration, deceleration, and lateral acceleration (see Table 1). The results showed a statistical difference in safety in longitudinal deceleration.

Table 1. WSRT for the longitudinal acceleration (long. acc.), longitudinal deceleration (long. dec.), and lateral acceleration (lat. acc.) between two NDRAs.

Rating	Direction	NDRA (Median)	Wilcoxon Signed-rank Test
DS Refinement	Long. Acc.	Reading (3.00) Watching Video (3.00)	z = -1.382, p = 0.167
	Long. Dec.	Reading (3.00) Watching Video (3.00)	z = -0.649, p = 0.516
	Lat. Acc.	Reading (3.00) Watching Video (3.00)	z = -1.511, p = 0.131
Comfort	Long. Acc.	Reading (2.00) Watching Video (2.00)	z = -0.263, p = 0.793
	Long. Dec.	Reading (2.00) Watching Video (2.00)	z = -1.414, p = 0.157
	Lat. Acc.	Reading (2.50) Watching Video (2.00)	z = -0.905, p = 0.366
Pleasantness	Long. Acc.	Reading (2.00) Watching Video (2.00)	z = 0.258, p = 0.796
	Long. Dec.	Reading (2.00) Watching Video (2.00)	z = -0.632, p = 0.527
	Lat. Acc.	Reading (2.00) Watching Video (2.00)	z = -1.604, p = 0.109
Safety	Long. Acc.	Reading (2.00) Watching Video (2.00)	z = -1.633, p = 0.102
	Long. Dec.	Reading (2.00) Watching Video (2.00)	z = -2.530, p = 0.011*
	Lat. Acc.	Reading (2.00) Watching Video (2.00)	z = 1.342, p = 0.180

* H_0 *was rejected, as indicated* (p<0.05)

3.2. Effort to engage in Non-Driving Related Activity (NDRA)

The mean value of participants' mental workload was plotted on the bar graph (see Fig. 4). The bar graph showed that participants required a higher mental workload during reading than watching a video.

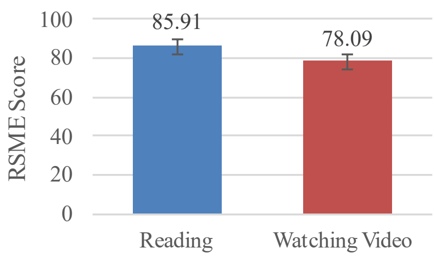

Fig. 4. Mean Rating Scale Mental Effort (RSME) score when engaging in Non-Driving Related Activities (NDRAs).

3.3. Motion sickness evaluation

The graph of the mean vehicle's and headband's $MSDV^2$ against time was plotted for the 10 minutes of 44 test drives (see Fig. 5). Only the longitudinal and lateral directions of the MSDV were shown due to the high correlation between motion sickness and frequencies below 0.5 Hz and peaks at 0.2 Hz [23-26].

The value of mean, standard deviation (SD), and coefficient of variance (CoV) of the Instrumented Vehicle's MSDV and participants' head movement for all 44 test drives were tabulated in Table 2. Since the value of SD was low (<1), the Instrumented Vehicle driven by Driving Wizard showed high reliability and consistency. It means that each participant experienced the induced force generated from the Instrumented Vehicle was about the same in all three axes direction (longitudinal, lateral, and vertical).

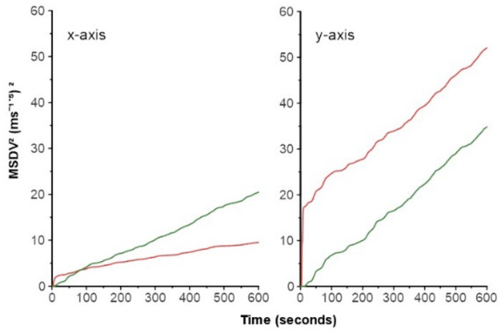

Fig. 5. Vehicle's (red) and headband's (green) MSDV with frequency-weighted acceleration in the longitudinal (x-axis) and lateral (y-axis) direction.

Table 2. Mean, SD, and CoV of MSDV for 44 test rides in three axes from the Instrumented Vehicle's and headband's accelerometer.

	Instrumented Vehicle's accelerometer			Headband's accelerometer		
	Mean ($ms^{-1.5}$)	**SD**	**CoV(%)**	**Mean ($ms^{-1.5}$)**	**SD**	**CoV(%)**
$MSDV_x$	3.05	0.74	24.19	4.31	1.46	33.87
$MSDV_y$	7.21	0.60	8.34	6.04	1.06	17.55
$MSDV_z$	1.36	0.83	61.20	2.37	0.86	36.29

The MSDV value of each participant from the test ride (vehicle) and headband for each NDRA was statistically analysed using the Wilcoxon Signed-rank Test. The results found a statistically significant difference between the vehicle's MSDV and the headband's MSDV for each direction (longitudinal, lateral, and vertical) (see Table 3).

Table 3. Wilcoxon Signed-rank Test for MSDV of the vehicle and head movement of the participant in three axes.

Construct	NDRA	Condition	Median	Wilcoxon Signed-rank Test
$MSDV_x$	Reading	Vehicle	2.94	$z = 3.198$,
		Headband	4.42	$p = 0.001$*
	Watching video	Vehicle	2.82	$z = 2.938$,
		Headband	3.65	$p = 0.003$*
$MSDV_y$	Reading	Vehicle	7.21	$z = -3.782$,
		Headband	6.08	$p < 0.0005$*
	Watching video	Vehicle	7.08	$z = -3.523$,
		Headband	6.15	$p < 0.0005$*
$MSDV_z$	Reading	Vehicle	0.90	$z = 3.230$,
		Headband	2.31	$p = 0.001$*
	Watching video	Vehicle	1.16	$z = 2.971$,
		Headband	2.13	$p = 0.003$*

* *H_0 was rejected, as indicated* ($p<0.05$)

3.3.1. Misery scale

The mean value of MISC scores expressed by participants at a 2-minute interval was plotted on a line graph during the drive simulation (see Fig. 6). Overall, the mean values when reading were slightly higher than when watching a video.

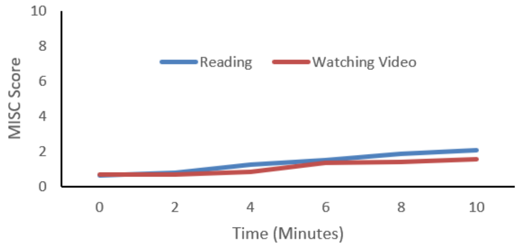

Fig. 6. Mean MISC scores over time.

3.3.2. Motion sickness assessment questionnaire

The Wilcoxon Signed-rank Test was done to determine whether any motion sickness was induced after the driving simulation when engaged in NDRA. The results showed differences in almost all the MSAQ constructs except for peripheral-related symptoms (see Table 4).

Table 4. MSAQ construct (gastrointestinal (G), central (C), peripheral (P), sopite (S), and overall (O)) between the pre-and post-driven phase.

Type of NDRA	MSAQ	Situation	Median (%)	Wilcoxon Signed-rank Test
Reading	G	Pre	11.11	$z = 2.624$, $p = 0.009$*
		Post	15.28	
	C	Pre	11.11	$z = 3.413$, $p = 0.001$*
		Post	16.67	
	P	Pre	11.11	$z = 1.640$, $p = 0.101$
		Post	12.96	
	S	Pre	11.11	$z = 3.632$, $p < 0.0005$*
		Post	19.44	
	O	Pre	11.11	$z = 3.764$, $p < 0.0005$*
		Post	19.01	
Watching Video	G	Pre	11.11	$z = 2.323$, $p = 0.020$*
		Post	11.11	
	C	Pre	11.11	$z = 2.494$, $p = 0.013$*
		Post	12.22	
	P	Pre	11.11	$z = -0.460$, $p = 0.646$
		Post	11.11	
	S	Pre	11.11	$z = 2.440$, $p = 0.015$*
		Post	19.44	
	O	Pre	12.50	$z = 2.353$, $p = 0.019$*
		Post	14.58	

* H_0 *was rejected, as indicated* (p<0.05)

3.3.3. Heart rate variability

The interaction between the within-subject (the phases of the experiment), between-subject (type of NDRAs engaged), and within-subject and between-subject of the measured HRV was performed by using two-way mixed ANOVA (see Table 5).

Table 5. The interaction of subject design using two-way mixed ANOVA for the measured HRV.

Measured RV	Two-way mixed ANOVA		
	Interaction of within-subject	Interaction of between-subject	Interaction between within-subject and between-subject
Mean of HR	✓	×	×
SD of HR	×	×	×
RMSSD	×	×	×
Pnn50	✓	×	×

✓ *Indicates that there has been an interaction*
× *Indicates that there has been no interaction*

4. Discussion

4.1. Validation of driving simulation

4.1.1. Power spectral density

PSD_x was generated by the Instrumented Vehicle's movement in longitudinal acceleration and deceleration driven by the Driving Wizard. PSD_y and PSD_z were developed in lateral (cornering) and vertical acceleration (road surface). The main frequency in PSD_x and PSD_y for the 44 tests was below 0.2 and 0.3 Hz, respectively (see Fig. 3). For PSD_z, the dominant frequency was below 0.03 Hz due to uneven road surfaces.

Since vibrations with less than 0.5 Hz are considered low frequency, they impose a low-frequency motion. Motion sickness is highly correlated with longitudinal and lateral motions with a frequency below 0.5 Hz and peaks at around 0.2 Hz [23-26].The amplitude of PSD_y was higher, as much as three times that of PSDx, due to magnitude during cornering being much more prominent than magnitude during longitudinal acceleration and deceleration.

4.1.2. Test ride analysis

The general results of the self-rating questionnaire showed no difference between the two NDRAs (reading and watching a video) ($p > 0.05$) in longitudinal acceleration and deceleration and lateral acceleration, except for safety rating in longitudinal deceleration ($p < 0.05$). In the DS Refinement rating, the participants stated that they were satisfied with the current induced force generated from Instrumented Vehicle when engaging NDRAs. They felt that Driving Wizard drove the longitudinal acceleration, longitudinal deceleration, and lateral acceleration, which were suitable for them to enjoy engaging NDRAs.

The steering wheel, gas pedal, and brake pedal are operated with low-amplitude, low-frequency motions as part of the defensive driving style [27]. So, the unpleasant acceleration or deceleration, such as sudden jerking, is not experienced by the participants so that they can enjoy the ride while engaging NDRAs.

Additionally, participants stated that they felt comfortable, pleasant, and safe when engaging in NDRAs. They believed this because they believed the "Defensive" type of movement to be more trustworthy [12, 28, 29], which reduced the likelihood of an accident. They comfortably enjoyed engaging NDRAs when driving by Driving Wizard without feeling worried about an accident.

The median score of comfort rating when engaging in reading as an NDRA was slightly higher than watching a video in lateral acceleration. A study by Isu et al. [30] about engaging NDRAs during car driving found that reading activity induced more uncomfortable feelings than watching a video. They stated that the uncomfortable feeling (motion sickness) experienced by participants was due to the exposure to the duration of the horizontal body oscillation [31]. When the participants engaged in reading as NDRA throughout the experiment session, the uncomfortable feeling experienced was probably from their body oscillation.

4.2. Effort to engage NDRA

From the RSME scale, the score of 85 and 78 indicates the average effort made by participants between considerable and great effort. Overall, the mean value of participants' actions when engaging in NDRA was higher during reading than watching a video. It means they put more effort and focus into reading than watching a video. The participants needed more concentration to analyse the medium when reading text (still image) compared to watching a video (moving image). So, the participants expected they feel more exhausted when reading than watching a video.

4.3. Motion sickness evaluation

4.3.1. Motion sickness dosage value

The dosage of motion sickness experienced by each participant in 44 driving was tabulated in three directions (see Table 2). The value of $MSDV_x$, $MSDV_y$, and $MSDV_z$ was obtained from the Instrumented Vehicle acceleration and deceleration in the longitudinal, lateral, and vertical directions, respectively. Due to the extremely low dosage of $MSDV_x$, the participants did not suffer motion sickness. However, in $MSDV_y$, mild motion sickness was produced by an instrumented vehicle driven by a driving wizard [32].

It was because the participant's bodies swayed more in higher magnitude in the lateral than longitudinal direction. The development of motion sickness is related to changes in body sway [33-35]. Moreover, there is a correlation between the head roll angle and lateral acceleration when being driven. Passengers' heads often lean toward lateral acceleration during corners. The passenger's head sways in a higher magnitude in the lateral direction than the longitudinal direction.

Hence, the passenger quickly experienced motion sickness. Wada et al. [36] and Wada and Yoshida et al. [37] found that a passenger experienced more motion sickness if s/he tilted their head against the centrifugal force. Although the participants were subjected to a low dose of motion sickness in the current study, they demonstrated they were comfortable using the suggested Defensive AV DS in a lateral acceleration (refer to Section 3.1.2). A more prolonged exposure (over 10 minutes) can provide a different outcome since the motion sickness is expected to increase.

From the head movement the values of headband MSDV were obtained from the head movement of each participant in three axes. Overall, the participants' head movement median value was higher on the x- and z-axis and lower on the y-axis than the Instrumented Vehicle's MSDV for both NDRAs. In the x- and z-axis, the higher value in the head movement was possibly due to the vehicle's movement during accelerating and braking in the longitudinal direction and uneven road in the vertical direction.

Additionally, since the accelerometer (headband) was worn on the head, the participant's head was easy to sway or move compared to the accelerometer at the centre of gravity of the Instrumented Vehicle. Even though the value of the headband was higher, the values generated from the headband and vehicle were considered slight or no motion sickness to be experienced by each participant [32]. Hence, they do not experience motion sickness from their head movement.

While in the y-axis, the median value of participants' head movement was lower than the Instrumented Vehicle's MSDV in both NDRAs. The lower value was probably due to the participant's effort and tendency to focus on engaging in driving by Driving Wizard. As the vehicle turns right or left during cornering, the participant attempts to maintain their head parallel to the position of the tablet to engage the NDRAs given.

As discussed in Section 4.2, on average, the effort to engage NDRAs was between 70 (considerable effort) and 90 (great effort). The value of 6 $ms^{-1.5}$ indicates that the motion sickness that each participant experienced from their head movement was mild [32]. Since the participants engaged NDRAs given in a moving vehicle, they hardly anticipated the vehicle movement. A theory about postural instability was found by Riccio and Stoffregen et al. [38]. They stated that motion sickness happens due to a lack of anticipation and reactions required to the new type of motion induced.

4.3.2. Misery scale

Throughout the 10-minute rides, participants' highest score of MISC stated during reading and watching a movie was 5 and 4, respectively. The value of 5 and 4 in MISC indicates that the participants experience motion sickness symptoms (dizziness, warmth, headache, stomach awareness, sweating, etc.) at the level of severe and medium, respectively. The results obtained were expected as the rides generated a mild motion sickness to be experienced by each participant, as discussed in Section 4.3.1.

The mean value of the MISC score during reading was slightly higher than watching a video (see Fig. 6). The participants stated that they felt more motion sickness during engaging reading as NDRA compared to watching video throughout the 10-minute drive. The participants who engage in reading as an NDRA experience more motion sickness than watching a video [39]. More concentration is needed when reading (still image) compared to watching a video (moving image). Also, with the help of sound effects when watching a video, the participants were a little distracted and more relaxed, making their concentration less. If participants were exposed to more prolonged driving, the value of the MISC score was expected to increase [40].

The sensory conflict theory introduced by Reason and Brand et al. [41] explained how motion sickness could be induced and experienced by the passenger when being driven in a moving vehicle. During engaging NDRAs, such as reading and watching a video in a moving vehicle, the eyes (visual system) do not sense the vehicle's movement. In contrast, the ear (vestibular) and body (somatosensory system) sense the vehicle movement. These conflicts developed an uncomfortable feeling known as motion sickness.

The factors discussed by Diels and Bos (2016) that make motion sickness occur, such as the situation of passengers incapable of predicting the future motion trajectory and the view of passengers when engaging NDRA, are most likely to play a part in motion sickness to develop and increase. As a passenger, s/he is hard to anticipate the movement of the vehicle (acceleration, deceleration, and cornering) since they are not controlling the pedals and steering. The passengers are more prone to develop MS than the driver because they lack control over the upcoming driving manoeuvres [42].

The development of motion sickness gets worse when the passenger is engaging NDRA while being driven. When engaging in an NDRA, such as reading and watching a video, passengers' view is limited when looking at their tablets. They are less aware of their surroundings when the vehicle moves, so their sensory system will conflict and develop motion sickness.

4.3.3. Motion sickness assessment questionnaire

The score of MSAQ constructs showed a difference between the two situations (pre-driven and post-driven) except for peripheral-related for both types of NDRA (see Table 4). The results showed that the participants experienced motion sickness when engaging both NDRA after driving by Driving Wizard ($p < 0.05$). Participants probably experienced motion sickness due to cornering when engaging NDRAs since the motion sickness induced by Instrumented Vehicle since the mild motion sickness generated as discussed in Section 4.3.1.

Based on the previous findings from Norzam et al. [7] that using the same route as in this study (same MSDV), there was no statistical difference between pre-and post-driven in MSAQ while doing nothing as NDRA. However, when reading and watching a video as NDRA, there was a statistical difference between pre-and post-MSAQ. The participants were expected to experience motion sickness when engaging in NDRA, such as reading and watching a video, since these activities make the passengers uncomfortable [39].

From the results, the highest difference (post-driven – pre-driven) for the MSAQ construct in the median score (%) was sopite-related for both NDRAs. The symptoms of sopite-related are feeling annoyed/related, drowsy, tired, and uneasy. The participants said they felt tired after 10 minutes of driving by Driving Wizard while engaging NDRAs. They felt so because reading and watching a video need some mental focus and concentration while engaging them, especially in a moving vehicle, as discussed in Section 4.2.

Additionally, from the Overall MSAQ construct (O), the median difference in reading (19.44% - 11.11% = 8.33%) was higher compared to watching the video (14.58% - 12.50% = 2.08%). It showed that reading activity imposed higher motion sickness after the driven phase. The higher motion sickness is due to the effect of engaging NDRA during the driving phase, as discussed in Section 4.3.2.

4.3.4. Heart rate variability

A further analysis was done using WSRT since there was an interaction of HR_mean (see Table 5). The results found a statistical difference between the pre-and during the-driven phase, and it was discovered that the mean HR of participants was increased during the-driven phase. Increasing HR stated that increased motion sickness was experienced by participants [29, 43, 44]. As the increase in MSDV (see Fig. 5) during the driven phase, the participants experienced an increasing motion sickness as they were exposed to the longer rides while engaging NDRAs given.

Additionally, there was a statistical difference between the pre-and post-driven phases from WSRT analysis. It was found that the participant's HR was decreased in the post-driven phase. The higher mean HR in pre-driven was probably because of early anticipation from participants toward the AV [45]. They presumed they would experience severe motion sickness when being driven by something new technology/system, especially when engaging NDRA.

The recorded Pnn50 also showed that there was an interaction within the subject. A further analysis was done using WSRT and found a statistically significant difference between pre-and during-driven phases. The results explained that the value of Pnn50 decreased during the phase. The declining Pnn50 value indicated that the participants experienced increasing motion sickness when engaging in NDRAs. Since Pnn50 is closely related to the parasympathetic nervous system, the decrement of parasympathetic nervous system activity has been shown to indicate the development of motion sickness [46-49].

5. Conclusions

Through a high consistency test ride, each participant experienced the induced force driven by Driving Wizard with Defensive AV driving style in three axes direction (longitudinal, lateral, and vertical acceleration and deceleration). The participants anticipated experiencing motion sickness when using NDRAs since the test rides produced a dose that each participant did not or experienced minimal motion sickness in the longitudinal direction but could suffer minor motion sickness in the lateral direction.

The data obtained in subjective (self-rating questionnaires), and objective (heart rate variability and head movement) measurements showed that participants experienced motion sickness during and after driving. Also, the results showed that the participants experienced more motion sickness when reading as NDRA than when watching a video.

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