Motion Sickness in Automated Vehicles with Forward and Rearward Facing Seating Orientations

Salter, S., Diels, C., Herriotts, P., Kanarachos, S. & Thake, D.

Original citation & hyperlink:
Salter, S, Diels, C, Herriotts, P, Kanarachos, S & Thake, D 2019, 'Motion Sickness in Automated Vehicles with Forward and Rearward Facing Seating Orientations' Applied Ergonomics, vol. 78, no. J, pp. 54-61.
https://dx.doi.org/10.1016/j.apergo.2019.02.001

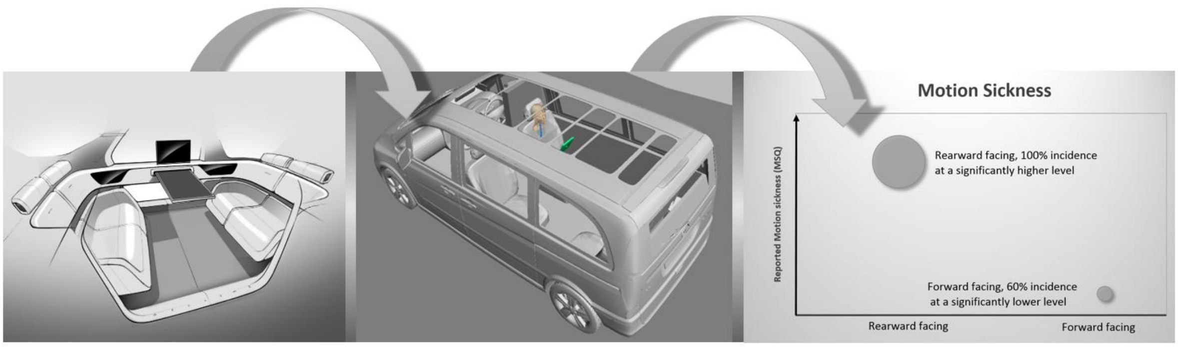
DOI 10.1016/j.apergo.2019.02.001
ISSN 0003-6870
ESSN 1872-9126

Publisher: Elsevier

Motion Sickness in Automated Vehicles with Forward and Rearward Facing Seating Orientations

Spencer Salter FIMechE MCSFS, Dr Cyriel Diels, Dr Paul Herriotts, Dr Stratis Kanarachos, Dr Doug Thake
Coventry University[1], Jaguar Landrover, Coventry University, Coventry University, Coventry University
salters@uni.coventry.ac.uk, cyriel.diels@coventry.ac.uk, pherriot@jaguarlandrover.com
stratis.kanarachos@coventry.ac.uk, doug.thake@coventry.ac.uk

Graphical Abstract



Abstract

Automated vehicles (AV's) offer greater flexibility in cabin design particularly in a future where no physical driving controls are required. One common concept for an automated vehicle is to have both forward and rearward facing seats. However, traveling backwards could lead to an increased likelihood of experiencing motion sickness due to the inability of occupants to anticipate the future motion trajectory. This study aimed to empirically evaluate the impact of seating orientation on the levels of motion sickness within an AV cabin. To this end, a vehicle was modified to replicate the common concept of automated vehicles with forward and rearward facing seats. Two routes were chosen to simulate motorway and urban driving. The participants were instructed to carry out typical office tasks whilst being driven in the vehicle which consisted of conducting a meeting, operating a personal device and taking notes. The participants conducted the test twice to experience both forward and rearward seating orientations in a randomised crossover design. Levels of sickness reported was relatively low with a significant increase in the mean level of sickness recorded when traveling rearwards. As expected, this increase was particularly pronounced under urban driving conditions. It is concluded that rearward travel in automated vehicles will compromise the passenger experience.

Keywords: Automated Vehicle, Motion Sickness, Seating Orientation

[1] Full time sponsored PhD research by Jaguar Landrover Ltd.

1 Introduction

Automated Vehicles (AV's) are now becoming a reality. Several pilot studies are underway with most Original Equipment Manufacturers (OEM's) declaring their intention to be part of an automated future. Numerous concepts are being revealed at motor and consumer electronic shows depicting flexible seating in an office like environment, Figure 1.

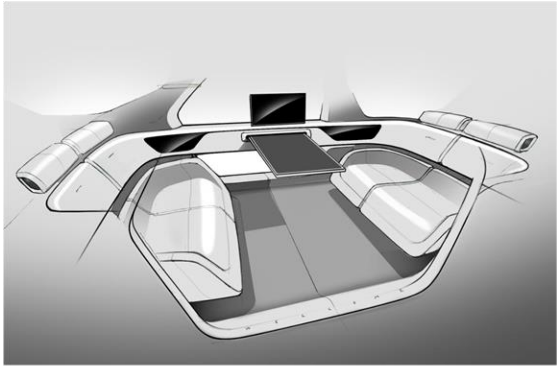


Figure 1 Common theme for Automated vehicle cabin (Image: JaguarLandrover)

Perhaps the prime objective of an automated cabin is to be able to 'multitask' within a journey and increase the inherent value of that journey by enabling additional productivity, enjoyment and improved well-being whilst being driven. Indeed commute satisfaction is significantly increased regardless of the mode of value add (St-Louis, Manaugh, Van Lierop, & El-Geneidy, 2014) Furthermore the 'time-cost' saving for journeys for AV's could be as high as 50% and 80% in some extreme cases when non-value add is reduced (MacKenzie, Wadud, & Leiby, 2014). It is therefore paramount to maximise the time available in an AV to be engaged in productive activities to fully realise the time-cost benefits. Therefore, the ability to engage in Non-Driving Related Tasks (NDRT) is an essential part of making the journey 'value-add' whilst maintaining or improving well-being.

To maximise productivity, many of proposed concepts depict fully flexible seating within an office-like environment. Enabling technologies such as large touch screens for digital input and centre tables are widely used in AV concepts. The driving task will in future be automated to manage the motion and flow safely with other road users in a public space thus leaving all occupants to be free to engage in NDRT's.

This poses many challenges, one significant being able to function with dexterous tasks whilst subjected to motion, (Diels et al., 2017). Whole body Vibration (WBV) has been shown to influence the effectiveness of reading whilst being subjected to motion typical of motor vehicle, (M J Griffin & Hayward, 1994). Additionally, performance was shown to be degraded in the use of a computer within dynamic environment, (Mansfield, Arora, & Rimell, 2007), (Narayanamoorthy & Huzur Saran, 2011). In one study it has been found that lateral whole body vibration at 4Hz is the most difficult for reading and writing tasks, it was also shown that it was more difficult at a table rather than tasks placed on the lap, (Sundström & Khan, 2008).

It has been argued comprehensively that the critical challenge to the acceptance of AV's will be motion sickness, (Diels & Bos, 2016). Motion sickness is a condition characterised by signs and symptoms such as (cold) sweating, pallor, flatulence, burping, salivation, apathy, and finally by nausea and retching (Reason & Brand, 1975). Motion sickness is known to affect some two thirds of the population at some point in their lives (Reason & Brand, 1975). According to ensory conflict theory, motion sickness occurs if the motion as sensed via our sensing systems (i.e. *sensed motion*) is different from what we expect them to be (i.e. *expected motion*). Motion sickness can also be described by postural *in*stability. Prolonged instability with the control of posture can cause motion sickness, (Riccio & Stoffregen, 1991). It is also suggested that oculocardiac reflex can also be used to describe motion sickness (Ebenholtz, Cohen, & Linder, 1994).

Turner & Griffin (1999a) that the exterior forward view from within the cabin to be influential in reducing motion sickness. It could be that predicting the future path of the vehicle trajectory from radially expanding optic flow reduces the build of motion sickness. Following from Griffin's findings it has also been shown recently that peripheral vision is key to the propensity of motion sickness which has significant implications for the design and positioning of in-vehicle displays and explained by its effect on reducing the conflict between sensed and expected motion (Kuiper, Bos, & Diels, 2018).

It is known that, in comparison to passengers, drivers in conventional vehicles are less prone to motion sickness being an integral part of the control loop for the vehicle motion. This is clearly demonstrated when drivers tilt their head into a bend, passengers are passive and exhibit a general trend for centripetal motion leaning with the motion in the opposite direction (Wada, Fujisawa, Imaizumi, Kamiji, & Doi, 2010). With the driver having an anticipation of motion leads to a good match between the expected and sensed motion and reduced motion sickness. (Rolnick & Lubow, 1991).

Any hindrance to anticipatory cues of future motion will increase motion sickness. Rearward facing seats prevent any real time view of the forward trajectory of the vehicle and limited indication from supplementary driver action cues (Human or Automated). The design of AV's should maximise the ability for occupants to anticipate the future motion path of the vehicle and minimise the likelihood of conflicting motion cues (Diels, 2014). Facing rearwards not only reduces the ability to anticipate the future motion trajectory, it also increases the likelihood of conflicting visual-vestibular motion cues when the outward vision is compromised by narrow rear and side windows, also referred to as Daylight Openings (DLO). As such, compared to forward seating orientations, traveling rearwards can be expected to increase the likelihood of motion sickness (Wada, 2016).

Recent literature has been limited to on-road testing of cars with only forward-facing seating configurations, there are *no* published studies as to the effect of seating rearwards. Notable studies that investigate forward seating positions include; M J Griffin & Newman, (2004), Turner & Griffin (1999a), Wada, Konno, Fujisawa, & Doi (2012). Turner & Griffin (1999a) investigated rearward seating in passenger coaches and found significantly increased mean illness ratings for seating backwards over forwards in passenger coaches. It should be noted that the study was limited to passenger coaches only, unknown duration and levels of provocative motion. The study also pre-dates the widespread use of mobile devices with connectivity and as such does not reflect the current or future trends of passenger transport.

The concept of undertaking office tasks in a vehicle has had little attention in the ergonomics literature. However, one notable study in the field looked at the repurposing of vehicle cabins to office spaces (Eost & Galer Flyte, 1998). This study however was limited to stationary vehicles with no motion but does provide useful evidence of the difficulties faced by business journeys, again this study predates the era of the mobile device. The study did however find that the vehicles were driven on average for 4 hours per day and 0.5 hours used for office tasks. This indicates a substantial productivity potential if the vehicle journeys were automated.

It has been estimated that there is a 6-12% increase in occurrence and severity of motion sickness within a conventional cabin driven automatically, due to the possibility of NDRT's (Sivak & Schoettle, 2015). This study is however based on empirical approximations. Kuiper *et* al. for example, have shown that auxiliary screen height alone can account for a 40% increase in sickness symptoms.

Anecdotally, many travellers have a preference not to face rearwards. Murphy, Wardman, & Magee (2013) found that 25% of passengers on trains believe that the direction of seating is important with 17% choosing not to sit facing rearwards at all. A significant preference for forward seating in train environments was also found by Han, Jung, Jung, Kwahk, & Park (1998).

Motion sickness measurement has historically been limited to subjective self-report questionnaires; the Pensacola Motion Sickness Questionnaires (MSQ), (Kennedy & Graybiel, 1965), Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lilienthal, 1993) and the Fast Motion Sickness (FMS) method (Keshavarz & Hecht, 2011). Additionally, the Misery Scale (MISC) was introduced in a Visually Induced Motion Sickness study (VIMS) by (Bos, de Vries, van Emmerik, & Groen, 2010). All subjective measures are generally reported after the symptoms have developed and are therefore reactive. Physiological measures such as HRV are widely used in studies with mixed results (Yokota, Aoki, Mizuta, Ito, & Isu, 2005), (Ohyama et al., 2007). Predictive measures are possible based on stimuli, environmental and task (Lawther & Griffin, 1987).

The purpose of this study is to understand the difference between rearward and front facing seating conditions and report any increase in recorded motion sickness within an automated vehicle concept within a real-world environment. The aim of this paper is to provide quantitative symptomatic motion sickness data for a known stimulus within an office setting regardless of any specific motion sickness theory. We hypothesise that rearward facing seats will generate an increased incidence and severity of motion sickness, this may be exacerbated by social seating.

2 Methods

2.1 Participants and Procedure

The study was conducted under local code of conduct and risk assessments and finally Coventry University Ethics P65727.

Participants were recruited from a pool of engineers within a large organisation. All were trained in automotive engineering with varying specialities. Participants were informed about the purpose and procedures of the study and signed an informed consent prior to commencing the study. They were informed that they could withdraw at any time with no recourse. They were not paid for the study over and above normal paid employment, no conflicts of interest were recorded. There were 20 participants in all, 9 females and 11 males with a mean age of 36 years (SD=13).

The route durations were split into 11 minutes and 17 minutes for motorway and urban driving respectively, with 5 minutes collection and drop off and 3-minute seat swap time, as illustrated in **Error! Reference source not found.**. It should be noted that the collection and drop off was similar to urban driving but limited to 15 mph speed limit and therefore generated minimal accelerations.

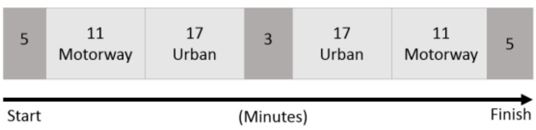


Figure 2 Stimuli duration, 5 (min) collection, 11 (min) motorway, 17 (min) urban, 3 (min) configuration, 17 (min) urban, 11 (min) motorway, 5 (min) drop off

Participants were collected in groups of three. They were positioned in the vehicle according to the test plan for seating configuration and direction of seating. They were then driven to the test location. This took approximately 5 minutes at low speeds. The participants were driven around the motorway section for 11 minutes. The vehicle then travelled to the urban route. The occupants were driven around for a further 17 minutes on the urban route. The tasks were completed within the 11 and 17-minute time windows. The vehicle was reconfigured for the alternative seating position according to the test plan, this took approximately 3 minutes. The vehicle was then driven in the reverse order so that participants had the same exposure for both drives. Once completed, participants were returned to the collection point. A single driver was used throughout and trained for the task so that position, speed and accelerations were consistent throughout.

2.2 Experimental vehicle

A 2008 Mercedes Vito mini-van was purchased and modified. Flexible seating was added to the rear cabin. The rear seats included integral seatbelts which could be swivelled with the chair on the rotation mechanism.

The driver was screened from the occupants in the cabin. The roof and the interior were modified to represent a future automated vehicle cabin concept.

The finished vehicle was to a high standard with minimal squeaks or rattles which can be distracting or mask motion. During the trials an observer was positioned in the left seat of row 2, Figure 3.

Figure 3 Plan view (Top), Rearward view (bottom Left). The forward view was partially obscured by the partition (bottom right)

2.3 Test route

The vehicle was driven on a private test track covered by relevant risk assessments and track regulations Figure 4, the weather was dry with mixed cloud cover during the summer with external air temperatures between 15-23 degrees Celsius.

Figure 4 Motorway route (left) and urban route (right, dashed indicates the smallest and largest bend radii)

The test route consisted of motorway and urban sections. The motorway section was part of a private three-lane high-speed circuit (Figure 4, left). The motorway route also included short simulated congestion, where the vehicle was slowed from 110kph down to 80kph five times per loop. Each loop was 6.0km in total. The urban route was a figure of eight track containing a stop at the intersections followed by a normal acceleration around the remainder of the circuit. The total length was 0.52km, with various radii of bends, smallest being ~12m radius and largest ~160m radius (see Figure 4, right). The urban route was driven smoothly at speeds less than 50kph.

2.4 Experimental conditions and study design

The vehicle used was intentionally configurable and the four experimental conditions considered are illustrated in Figure 5. These were, short (A1, A3) and long cabin (A2, A4), (A1, A2) having 0° inboard rotation and (A3, A4) having 10° inboard rotation. The participants undertook the test twice to experience either 0 or 10° for short or long configurations. All participants undertook a forward and rearward seat with randomised cabin length and angle of inclination. The left or right seat was not considered as a controlled variable in the rearward condition, the rear view was similar from both seats. Forward seating was limited to the right seat with the observer seated on the left (chosen for the observer's wellbeing and comfort due to repeated exposure). The forward view was restricted by the driver partition directly ahead for the forward right seat. Each participant completed the urban and motorway drive twice, once facing forward and once facing rearward, the order of which was counterbalanced to avoid any order effects. Questionnaires for this and other studies were completed as soon as the trial finished. Verbatim comments were noted throughout by the observer.

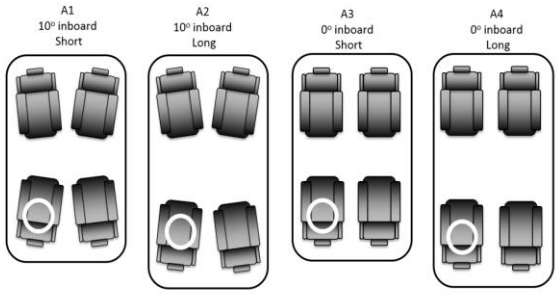


Figure 5 The four experimental conditions evaluated. (A1) short cabin with and (A3) without 10° inboard rotation; and (A2) long cabin with and (A4) without 10° inboard rotation, observer location (circle).

2.5 In-vehicle tasks

The participants were asked to carry out office tasks whilst being driven in the vehicle. This consisted of conducting a meeting, operation of a personal device looking down and taking notes as they would normally do in an office environment. The participants were free to carry out tasks to be as productive as possible for their journey in a business environment. All participants were colleagues within a large organisation that would normally conduct business meetings together in typical office environments. The type and duration of task was not controlled within this experiment other than participants conducted a sham meeting throughout the duration of the test.

2.6 Measures

2.6.1 Motion sickness susceptibility

Participants were asked to complete a MSSQ-Short sickness susceptibility questionnaire before completing the study (Golding, 2006).

2.6.2 Motion sickness

Motion sickness was measured using a four-point scale version of the Simulator Sickness Questionnaire (SSQ) after each drive (see Table 1). No weightings were applied to individual symptoms for this study and the total SSQ score uses the mean of individual symptoms across all participants.

Table 1 Modified SSQ items

	None (0)	Slight (1)	Moderate (2)	Severe (3)
General discomfort				
Fatigue				
Headache				
Eyestrain				
Difficulty focussing				
Increased salivation				
Sweating				
Nausea				
Difficulty concentrating				
Fullness of head				
Blurred vision				
Dizziness (eyes open)				
Dizziness (eyes closed)				
Vertigo				
Stomach awareness				
Burping				

2.6.3 Ambient Temperature

The temperature was monitored due to the potential for excessive heat build due to the extensive glazed area of the donor vehicle and reduced ventilation control. Temperature was monitored using a mobile two channel temperature logging device (PerfectPrime HT165) for ambient temperature and relative humidity (RH). Two measurements were taken between the two sets of seats simultaneously, one on the device and the other via the remote wired sensor.

2.6.4 Motion

Accelerations within the urban and motorway drives were recorded using tri-axial steady state accelerometers located a seat fixing to the vehicle floor. The measurement device utilised MPU6050 6 axis + temperature module, Bosch BM255 Accelerometer and Bosch BMG160 Gyroscope that stored data to an SD Card. The co-ordinate system used throughout is positive X to the front of the vehicle, +Y to the left, +Z vertically up in the vehicle.

Acceleration data was post-processed using a band pass filter (f=0.0005-0.16Hz, 2ndorder Tschebyscheff 0.5dB), (Kabal & Ramachandran, 1986). The low pass filter used does not reduce the steady state component like ISO2631 W_f weightings and is closely aligned to findings by Donohew and Griffin for provocative lateral motion (Donohew & Griffin, 2004). The data was unfiltered by any weightings from ISO2631(1997) or British Standard (BS6841, 1987).

2.7 Transport modality

Participants were also asked to share their transport history by answering the question: "In the past year how many times have you used the following types of transport?" for the following modes; car-driver, passenger row 1, passenger row 3, bus/coach, taxi facing forwards and taxis facing rearward, against a five point scale; (Daily, Frequently, Occasionally, Rarely, Never) This question was included to understand the likely exposure of the participants to past rearward automotive transport (Currently only possible in some taxis).

2.8 Statistical methods

Statistical data analysis was performed using Minitab Version 18. Comparisons between configurations used either ANOVA, two sample and paired T-Tests and also Kruskal-Wallis test for non-parametric data. Multivariate MANOVA was utilised (Wilk's test) for

3 Results

3.1 Stimuli

The stimuli levels for the motorway and urban routes are shown in Figure 6. The stop-start section within the motorway route encouraged fore-aft accelerations. These were not significantly different to those recorded on the urban route (see Table 2). The higher speed on the motorway section induced more float and vertical motion compared to the urban route leading to marginal statistical significance. The lateral motion for the urban and motorway route was significantly different using a t-test (t=7.9, p<0.001). The urban route used a figure of eight layout with various radii and induced more yaw and lateral excitation than the motorway route. For comparison, 78 miles of train excitation has been included, measured between Birmingham and Liverpool using the same measurement equipment. All directions were significantly less than the urban route, Table 2.

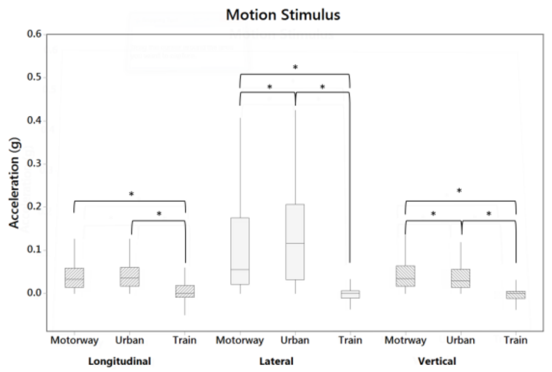


Figure 6 Acceleration levels (f_{max}=2.0 Hz, g) unfiltered in the time domain, X (longitudinal), Y (lateral), Z (Vertical), including train comparative data (Birmingham to Liverpool)

Table 2 Motion comparisons for the Urban and Motorway and Trains, Accelerations (g) (Time domain)

fmax=2.0 Hz	*X Longitudinal (g)*		
	Motorway	***Urban***	***Train***
Mean	0.042	0.045	0.0043
SD	0.04	0.04	0.03
T [*p*]	-1.84 [>0.05 (NS)]		
T [*p*]		38.25 [<0.001]	
T [*p*]		56.92 [<0.001]	
	Y Lateral (g)		
	Motorway	***Urban***	***Train***
Mean	0.1	0.13	-0.002
SD	0.103	0.098	0.02
T [*p*]	-7.89 [<0.05]		
T [*p*]		50.64 [<0.001]	
T [*p*]		61.96 [<0.001]	
	Z Vertical (g)		
	Motorway	***Urban***	***Train***
Mean	0.046	0.04	-0.009
SD	0.039	0.036	0.03
T [*p*]	5.54 [<0.05]		
T [*p*]		51.42 [<0.001]	
T [*p*]		81.07 [<0.001]	

Average RMS of lateral accelerations was 0.27 (g) ±0.02, indicating peak variability of 11% across all tests as a result of the specified route and driver training.

3.2 Susceptibility results

The MSSQ-Short data recorded scores between 16th and 81st percentiles with an overall mean of 45th percentile susceptibility for this sample against the wider population.

3.3 Transport modality

Figure 7 shows the participant group distribution for recent transport modality. The participant sample indicated that they were mostly daily drivers and travelled less than once a month in a rearward facing seat in a Taxi. The total group was dominated by drivers showing a significant difference to the responses for being either a row 1, 2 or row 3 passenger as indicated by two-sample t-test (t=5.1, p<0.001, t=10.7, p<0.001, t=16.4, p<0.001) respectively. There was also a significant difference between the responses for forward and rearward positions in London Black Cab Taxis, two sample t-test yielded (t=2.65, p<0.05). Practically, the participants would be more likely to use the forward-facing seats using a London Black Cab taxi with low occupancy noting that the rearward facing seats are fold away and used typically with four or more passengers.

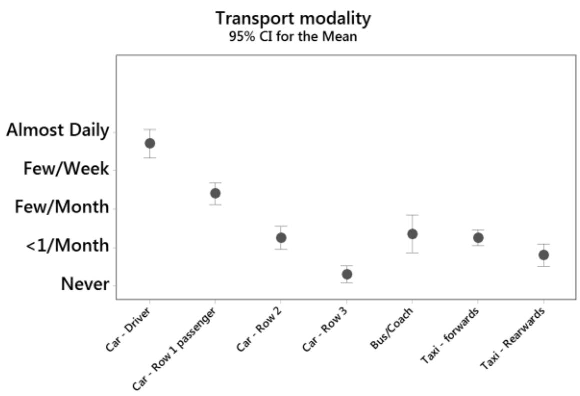


Figure 7 Transport modality for the participant group.

3.4 Multivariate analysis

Completing a MANOVA analysis across seating position (left, right), seating orientation (Forward/ Rearwards), experiment order (run 1, run 2) and seating condition (0° inclination + short spacing, 0° inclination + long spacing, 10° inclination + short spacing , 10° inclination + long spacing), Table 3, Figure 8 and Figure 9.

Table 3 Multivariate analysis MANOVA

Variable	Wilk's	F	p
Spacing (Short, Long)	0.9	3.33	>0.05
Inclination angle (0°, 10°)	1.0	0.18	>0.05
Orientation (Forward/Rearward)	0.8	7.26	<0.05
Experiment order	1.00	0.03	>0.05
Seat (Left/Right)	0.98	0.43	>0.05

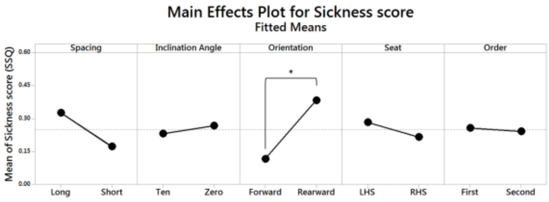


Figure 8 Main effects, mean sickness scores (SSQ)

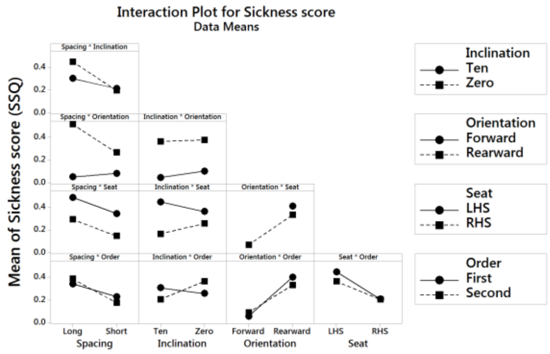


Figure 9 Interactions, mean sickness scores (SSQ)

3.5 Univariate: Order effects

Participants experienced two seating positions during the study; there was no significant difference found between the two runs based on the order when combining both forward and rearward seating positions (t=0.53, p>0.05, mean=0.3, SD=0.57, mean=0.27, SD=0.55) for first and second runs respectively.

3.6 Univariate: Motion sickness with different seating angles and spacing.

Results from the four possible seating configurations, short 0° rotation, short 10° rotation and long cabin 0° and long cabin 10° showed no significant difference for the incidence of sickness. The forward and rearward scores were aggregated into one data set per configuration, A1-A4 (see Figure 5). A Kruskal-Wallis test showed no significant differences between all possible combinations of seating configurations for motion sickness levels (H=3.349, N=60, p>0.05).

3.7 Univariate: Motion sickness from forwards and rearwards facing seats

By analysing the data set for seating orientation from the four conditions it can be shown that the rearward facing seating, regardless of inclination angle, leads to moderate sickness experienced by some participants for the rearward facing position (Mean=0.38, SD=0.64), whereas almost no sickness was reported for the forward condition (Mean=0.054, SD=0.23) (see Figure 10). This difference was found to be statistically significant (t=8.27, p<0.001, paired samples t-test). Figure 11 shows the individual SSQ items and indicate an increase across all symptoms.

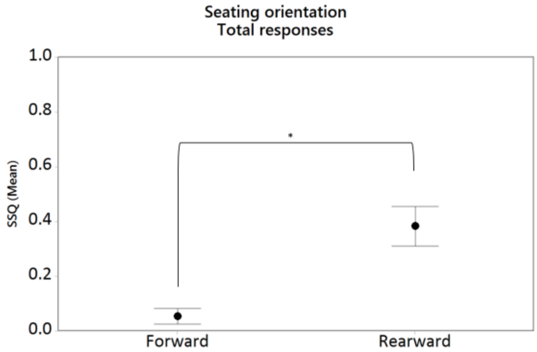


Figure 10 Mean SSQ score as a function of forward and rearward travel

Within this study, 100% of participants that faced rearwards reported some level of motion sickness compared to 60% of participants indicating a much lower level of sickness for facing forwards under the same conditions. Additionally, 75% of participants reported slight to moderate nausea facing rearwards whereas only 10% reported slight nausea facing forwards.

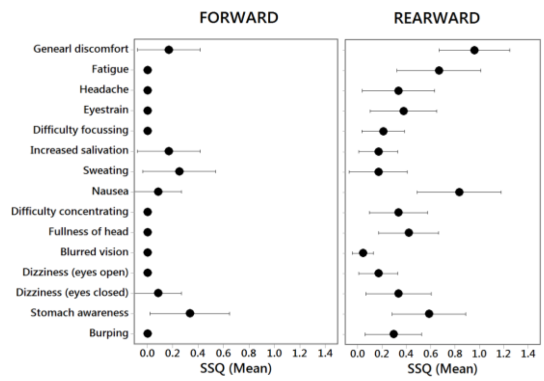


Figure 11 Mean SSQ item scores (±CI) when traveling forward (left) and rearward (right)

3.8 Verbatim comments

During the experiment, participants were asked several questions, predominantly around the usability and experience of the automated vehicle concept. The consensus was that the layout was good, albeit limited by motion sickness feelings that were observed during this study. There was a unanimous view that facing rearwards in an urban driving environment was unpleasant with a preference to sit in a forward-facing condition. This is congruent with train seating preferences.

Most participants commented positively towards the levels of vision, the size of the windows and the spacious feeling within the vehicle. Comments noted by participants when facing rearwards during this study;

"Excellent layout, nice social interaction. Space to stretch out. But feel queasy / sick"

"High speed track period not an issue, discomfort felt when driving the "windy" period, onset of nausea (very mild) in stomach"

"A bit worse than facing forward because I did not feel well, better when I was looking up again to see the environment outside, often checking emails."

"As I felt uncomfortable I would not want to use emails or phones as it would make me feel worse"

"Wouldn't want to read a book for motion sickness"

"View of out rear window disconcerting going around corners"

"I did not like the vision out of the rear window - slight travel sickness when manoeuvring at low speed. Side vision was wanted, less obstructed."

"..no ability to see forward. Would want to see surroundings in front to understand situation (e.g. traffic) and prevent sickness"

4 Discussion

This study showed that the participants within this study reported a significant increase in motion sickness symptoms when travelling facing rearwards on a combined urban and motorway route. In both cases the levels of sickness were relatively low. The participants within this study were all adults, with an engineering background and average susceptibility. However, there is no reason to believe that these results are not typical of a wider population.

The benefits of automated vehicles will be quickly eroded if journeys are disrupted by motion sickness leading to slower driving and or stopping completely. This could limit the acceptance of AV's and indeed driven vehicles with flexible seating. Trains generally are accepted for rearward facing travel noting that 17% will not sit rearwards and this is with significantly lower levels of provocative motion. It has been shown here that road vehicles are subjected to significantly higher levels of acceleration and does limit the effectiveness of multitasking exacerbated by relative motion between the occupant, objects and the vehicle.

Further research is needed to determine a unified complex aggregation of motion sickness weightings for driverless vehicles to include vehicle motion for the 6 degrees of freedom. Habituation may be key for the acceptance of AV's, further understanding regarding expected improvements for random exposures would be beneficial.

Multivariate analysis of this present study showed that only the seating orientation (forwards and rearwards) leads to a significant change in sickness scores. The seating angle made no statistically significant effect with respect to motion sickness with no significant difference observed between long, short separations and inclined angles. It should be noted that only 0 and 10° of inclination was used in this study. Larger inclination angles could make more of a difference by coupling directions together. For example, occupants will observe both lateral and fore aft acceleration components from a simple braking or forward acceleration manoeuvre. Repeats of this study or similar with larger angles would be useful in further understanding flexible seating (noting that real-world testing requires adequate risk assessments and be in keeping with current legislation regarding restraint systems).

The seat spacing (long and short) configurations showed slight significance ($p=0.078$) with the long configuration generating higher sickness scores. This is expected and congruent with findings by Griffin in that the rear of vehicles can be more provocative for motion due to centripetal effects (Turner & Griffin, 1999b). Meaning that there may be confounding effects whereby particular seating position could induce more provocative motion due to geometric effects. Distance from the steered yaw center of the vehicle will influence the observed lateral motion for example.

Within this study, gaze direction was not controlled, the participants free to view any direction that was necessary to conduct a business meeting within the vehicle. It would be expected that, if gaze direction were controlled to either limit or maximise the peripheral and external view the sickness scores would be higher for the rearward facing gaze down and lowest with forward facing gaze up congruent with findings by Kuiper.

In this study the donor vehicle had increased rearward field of view with more sky, horizon and road visible than the forward seating potion.

Conclusions from (Michael J Griffin & Newman, 2004) would suggest that the improved exterior view and may lead to lower sickness and incidence if driven in reverse using this vehicle design, noting that future AV's maybe omnidirectional. However, currently the rear view in conventional vehicles are generally more restricted and limit the external view and lead to increased sickness for a rearward seated occupant. Within conventional vehicles, it could be that future designs may need to adopt a balanced DLO attribute for the front and rear. This may challenge conventional design cues and indeed acceptance. Add to this the need for aerodynamic properties for higher efficiency at speed, then the balance of glazing area, design and aerofoil shape will be an important compromise for wellbeing within future AV's containing flexible seating.

Percentage increases in productivity have recently been argued lower by Singleton, (Singleton, 2018). He suggests that the actual realised benefits could be lower than those quoted in the literature based on high levels of uncertainty around the functionality of AV's, familiarity and general motivations of the occupants. If productivity is a true driver for automated vehicles, then this study has shown that motion sickness when facing rearwards can limit productivity in addition to the primary comfort and wellbeing of occupants. Comments from the participants suggested that the forward and rearward seating arrangement was beneficial for business activities and would most likely increase productivity and the inherent value of the journey. However, some noted a level of difficulty when facing rearwards using emails on mobile devices more so than facing forward. Perceptions of value add or feelings towards the layout of the vehicle may be different if, for example, the study was repeated in a family or social setting noting the experiment was conducted during working hours and a business context. Some participants noted that completing dexterous task was difficult whilst under motion. Hand held operation was slightly better than vehicle fixed operation due to the relative occupant to vehicle motion. British Standard (BS6841, 1987) provides some guidance for limits of vibration for reading tasks and should be used to position reading and input devices such that the levels of exposed vibration allow the effective use of NDRT technology. It has also been found that lateral low frequency motion is detrimental to visual-motor control for a seated occupant more so than vertical motion in a study by (Allen, Jex, & Magdaleno, 1973). It is therefore important that assistance features are included in future AV's. For example, rests and supports close to input points would be useful to facilitate accurate implementation of tasks whilst subjected to motion.

Habituation is a known and practiced remedy to motion sickness using controlled and gradual exposure to provocative motion described by (McCauley, Royal, Wylie, O'Hanlon, & Mackie, 1976). All participants were relatively new to rearward facing motion and therefore may be suitable for adaptation using neural plasticity, (Ramaswami, 2014). It is not known how many or the duration of repeat exposures would be necessary to balance reported sickness of forward and rearward seating under the same conditions. It is also unclear if random exposure with normal use of AV's would lead to effective habituation in the same way as clinical studies are described in the literature. It could be that after a small number of exposures that occupants would become less susceptible and familiar with rearward seating. If this is the case, then careful management of expectations will be necessary in the deployment of AV's in a public setting, particularly if flexible seating is an option.

Rearward seating has been an option in modern trains since their introduction. However, trains have significantly less provocative motion than road vehicles negotiating urban roads and as such rearward seating has been accepted by many for nearly 200 years (noting that some have an aversion to facing rearwards). Modern high-speed AV's will, in addition to longitudinal motion from traffic also enforce low frequency provocative lateral motion when negotiating variable radii curves at speed.

Travelling rearwards on motorways was less problematic according to the verbatim comments from this study and is congruent with the reduced levels of lateral acceleration. Most of the negative comments by the participants were that low speed manoeuvres on the urban route were felt to be the most provocative with 100% of participants indicating increased levels of sickness facing rearwards compared to 60% for the forward-facing condition. Some participants commented specifically about the desire for anticipatory motion information from the external environment. Another commented that the rear scene was disconcerted travelling around corners. On the drive to the test track when facing rearward, it was noted that other road user's pulling up to the vehicle appeared to close in quickly and was again disconcerting. This phenomenon was reduced with repeated exposure and increased trust on the return from the test track.

Additional cues to future motion could mitigate this to some degree such as listening to the navigation, engine tone, directional indicator 'tic – tocs' by providing additional information as to the future motion path of the vehicle, (Diels, Cieslak, & Schmidt, In preparation.). The plethora of NDRT's and multi-tasking opportunities that feature in many of the concepts for AV's could limit the anticipatory antidote for motion sickness, particularly if the occupants are engaged deeply with a task and perhaps miss the cues on offer. Considering that sensory arrangement theory is bound by the observed and sensed motion, sitting rearwards may exacerbate the conflict with complex and contradictory visual scenes for a known or expected stimuli. It has been proven that by providing additional anticipatory cues to flight imagery leads to reduced motion sickness in a forward direction, (Feenstra, Bos, & Van Gent, 2011), ergo by removing or reducing anticipatory information may also increase motion sickness symptoms.

Additional wearable mitigation devices could also help negate the effect of seating rearwards whilst conducting NDRT's within an AV environment. These however are not without compromise; cost, convenience and comfort. It may be that such devices will be needed as part of an effective habituation program during the transition into AV's from conventional vehicles.

This present study was conducted using a human driver with conventional vehicle controls. It should also be noted that the transition to Battery Electric Vehicles (BEV's) and full AI / Algorithmic vehicle control could offer new benefits of smoothness and repeatability. Further understanding of vehicle control and propulsion with respect to motion sickness is key for the driverless revolution and worthy of further study.

5 Conclusion

It is concluded that rearward travel in automated vehicles will compromise the passenger experience leading to increased motion sickness particularly within low speed urban environments.

6 References

Allen, R. W., Jex, H. R., & Magdaleno, R. E. (1973). *Manual control performance and dynamic response during sinusoidal vibration*. SYSTEMS TECHNOLOGY INC HAWTHORNE CA.

Bos, J. E., de Vries, S. C., van Emmerik, M. L., & Groen, E. L. (2010). The effect of internal and external fields of view on visually induced motion sickness. *Applied Ergonomics*, *41*(4), 516–521. https://doi.org/10.1016/j.apergo.2009.11.007

BS6841. (1987). *Guide to Measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock*. *British Standard*.

Diels, C. (2014). Will Autonomous Vehicles Make Us Sick? *Contemporary Ergonomics and Human Factors*, (October 2014), 301–307. https://doi.org/10.13140/RG.2.1.1461.0087

Diels, C., & Bos, J. E. (2016). Self-driving carsickness. *Applied Ergonomics*, *53*, 374–382. https://doi.org/10.1016/j.apergo.2015.09.009

Diels, C., Cieslak, M., & Schmidt, E. (n.d.). The effectiveness of anticipatory auditory motion cues in reducing motion sickness in automated vehicles. *In Press (2018)*.

Diels, C., Erol, T., Kukova, M., Wasser, J., Cieslak, M., Miglani, A., … Bos, J. (2017). Designing for Comfort in Shared and Automated Vehicles (SAV): a Conceptual Framework, (June), 1–8.

Donohew, B., & Griffin, M. J. (2004). Motion sickness : Effect of the frequency of Motion Sickness : Effect of the Frequency of Lateral Oscillation, *75*(September 2004), 649–656.

Ebenholtz, S. M., Cohen, M. M., & Linder, B. J. (1994). The possible role of nystagmus in motion sickness: A hypothesis. *Aviation Space and Environmental Medicine*, *65*(11), 1032–1035. Retrieved from https://www.scopus.com/inward/record.uri?eid=2-s2.0-0028150941&partnerID=40&md5=45766a09a3be7be33003f3215246baa8

Eost, C., & Galer Flyte, M. (1998). An investigation into the use of the car as a mobile office. *Applied Ergonomics*, *29*(5), 383–388. https://doi.org/10.1016/S0003-6870(98)00075-1

Feenstra, P. J., Bos, J. E., & Van Gent, R. N. H. W. (2011). A visual display enhancing comfort by counteracting airsickness. *Displays*, *32*(4), 194–200. https://doi.org/10.1016/j.displa.2010.11.002

Golding, J. F. (2006). Motion sickness susceptibility. *Autonomic Neuroscience: Basic and Clinical*. https://doi.org/10.1016/j.autneu.2006.07.019

Griffin, M. J., & Hayward, R. A. (1994). Effects of horizontal whole-body vibration on reading. *Applied Ergonomics*, *25*(3), 165–169.

Griffin, M. J., & Newman, M. M. (2004). An experimental study of low-frequency motion in cars. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, *218*(11), 1231–1238. https://doi.org/10.1243/0954407042580093

Griffin, M. J., & Newman, M. M. (2004). Visual field effects on motion sickness in cars. *Aviation Space & Environmental Medicine*, *75*(9), 739–748.

Han, S. H., Jung, E. S., Jung, M., Kwahk, J., & Park, S. (1998). Psychophysical methods and passenger preferences of interior designs, *29*(6), 499–506.

Kabal, P., & Ramachandran, R. P. (1986). The Computation of Line Spectral Frequencies Using Chebyshev Polynomials.

Kennedy, R. S., & Graybiel, A. (1965). *The Dial test: A standardized procedure for the experimental production of canal sickness symptomatology in a rotating environment*. NAVAL SCHOOL OF AVIATION MEDICINE PENSACOLA FL.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator_Sickness_Questionnaire. *The International Journal of Aviation Psychology*. https://doi.org/10.1207/s15327108ijap0303_3

Keshavarz, B., & Hecht, H. (2011). Validating an efficient method to quantify motion sickness. *Human Factors*, *53*(4), 415–426. https://doi.org/10.1177/0018720811403736

Kuiper, O. X., Bos, J. E., & Diels, C. (2018). Looking forward: In-vehicle auxiliary display positioning affects carsickness. *Applied Ergonomics*, *68*(August 2017), 169–175. https://doi.org/10.1016/j.apergo.2017.11.002

Lawther, A., & Griffin, M. J. (1987). Prediction of the incidence of motion sickness from the magnitude, frequency, and duration of vertical oscillation. *The Journal of the Acoustical Society of America*, *82*(3), 957–966. https://doi.org/10.1121/1.395295

MacKenzie, D., Wadud, Z., & Leiby, P. (2014). A first order estimate of energy impacts of automated vehicles in the United States. In *Transportation research board annual meeting* (Vol. 93).

Mansfield, N., Arora, Y., & Rimell, A. (2007). Computer use on moving trains: which pointing device? *Contemporary Ergonomics*, *2007*, 255.

McCauley, M. E., Royal, J. W., Wylie, C. D., O'Hanlon, J. F., & Mackie, R. R. (1976). *Motion sickness incidence: Exploratory studies of habituation, pitch and roll, and the refinement of a mathematical model*. Canyon Research Group Inc Goleta Ca Human Factors Research Div.

Murphy, P., Wardman, M., & Magee, A. (2013). Valuing Different Seating Layouts for Rolling Stock on. In *European Transport Conference* (pp. 1–23).

Narayanamoorthy, R., & Huzur Saran, V. (2011). Error analysis of task performance with laptop in vibration environment. *Computers in Human Behavior*, *27*(6), 2263–2270. https://doi.org/10.1016/j.chb.2011.07.005

Ohyama, S., Nishiike, S., Watanabe, H., Matsuoka, K., Akizuki, H., Takeda, N., & Harada, T. (2007). Autonomic responses during motion sickness induced by virtual reality. *Auris Nasus Larynx*, (34), 303–306. https://doi.org/10.1016/j.anl.2007.01.002

Ramaswami, M. (2014). Perspective Network Plasticity in Adaptive Filtering and Behavioral Habituation. *Neuron*, *82*(6), 1216–1229. https://doi.org/10.1016/j.neuron.2014.04.035

Reason, J. T., & Brand, J. J. (1975). *Motion Sickness*. Oxford, England: Academic Press.

Riccio, G. E., & Stoffregen, T. A. (1991). An ecological Theory of Motion Sickness and Postural Instability. *Ecological Psychology*. https://doi.org/10.1207/s15326969eco0303

_2

Rolnick, A., & Lubow, R. E. (1991). Why is the driver rarely motion sick? The role of controllability in motion sickness. *Ergonomics*, *34*(7), 867–879. https://doi.org/10.1080/0014013910896483 1

Singleton, P. A. (2018). Discussing the "positive utilities" of autonomous vehicles: will travellers really use their time productively? *Transport Reviews*, *0*(0), 1–16. https://doi.org/10.1080/01441647.2018.147 0584

Sivak, M., & Schoettle, B. (2015). Motion sickness in self-driving vehicles, (April), 1–13. Retrieved from https://deepblue.lib.umich.edu/handle/2027 .42/111747

St-Louis, E., Manaugh, K., Van Lierop, D., & El-Geneidy, A. (2014). The happy commuter: A comparison of commuter satisfaction across modes. *Transportation Research Part F: Traffic Psychology and Behaviour*, *26*(PART A), 160–170. https://doi.org/10.1016/j.trf.2014.07.004

Sundström, J., & Khan, S. (2008). Influence of stationary lateral vibrations on train passengers' difficulty to read and write. *Applied Ergonomics*, *39*(6), 710–718. https://doi.org/10.1016/j.apergo.2007.11.00 9

Turner, M., & Griffin, M. J. (1999a). Motion sickness in public road transport: Passenger behaviour and susceptibility. *Ergonomics*, *42*(3), 444–461. https://doi.org/10.1080/001401399185586

Turner, M., & Griffin, M. J. (1999b). Motion sickness in public road transport: The effect of driver, route and vehicle. *Ergonomics*, *42*(12), 1646–1664. https://doi.org/10.1080/001401399184730

Wada, T. (2016). Motion Sickness in Automated Vehicles. *International Symposium on Advanced Vehicle Control 2016*, *2016*. https://doi.org/10.1007/978-3-319-40503-2

Wada, T., Fujisawa, S., Imaizumi, K., Kamiji, N., & Doi, S. (2010). *Effect of driver's head tilt strategy on motion sickness incidence*. *IFAC Proceedings Volumes (IFAC-PapersOnline)* (Vol. 11). IFAC. https://doi.org/10.3182/20100831-4-FR-2021.00035

Wada, T., Konno, H., Fujisawa, S., & Doi, S. (2012). Can Passengers' Active Head Tilt Decrease the Severity of Carsickness? *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *54*(2), 226–234. https://doi.org/10.1177/0018720812436584

Yokota, Y., Aoki, M., Mizuta, K., Ito, Y., & Isu, N. (2005). Motion sickness susceptibility associated with visually induced postural instability and cardiac autonomic responses in healthy subjects. *Acta Oto-Laryngologica*, *125*(3), 280–285. https://doi.org/10.1080/0001648051000319 2