A Preliminary Investigation of the Association Between Motion Sickness Response and Task Performance and Engagement

Monica L.H. JONES[1*], Sheila M. EBERT[1] and Matthew P. REED[1]

[1] University of Michigan Transportation Research Institute, Ann Arbor, MI, USA

* Corresponding author. Tel.: +1-734-936-0788. E-mail address: mhaumann@umich.edu

Abstract Vehicle automation will provide the opportunity for occupants who were formerly full-time drivers to become passengers for some or all of their journey. Freed of the constraints of the driving task, passengers will have a much larger behavioral repertoire, including extensive use of handheld devices. Passengers often experience motion sickness, particularly when performing visual tasks such as reading or using a handheld device. However, little quantitative data is available on association between motion sickness response and task engagement in passenger vehicles.

In recent and ongoing studies, UMTRI has developed a vehicle-based methodology to evaluate motion sickness susceptibly in passenger vehicles. This work has been motivated by the opportunities in the design of highly automated vehicles to manage motion sickness through changes in vehicle dynamics and interior configuration, as well as other countermeasures. The in-vehicle methodology includes simultaneous measurements of vehicle motion and the passenger's psychophysical, kinematic and physiological response during typical on-road driving conditions.

This paper describes a preliminary investigation to quantify the relationship between passenger motion sickness and non-driving related task performance and engagement during an on-road vehicle exposure. Data were gathered from 22 participants who self-reported a range of the motion susceptibility levels prior to testing across urban and highway routes. The current protocol is part of a larger research effort to gather passenger response data from road vehicles to inform the design of automated vehicles.

Keywords: Motion Sickness; Passenger Activities; Task Engagement; Automated Vehicles

1 Introduction

Automated vehicles will provide the opportunity for occupants who were formerly full-time drivers to become passengers for some or all of their journey. These occupants will have a much larger behavioral repertoire when freed of the constraints of the driving task. Passengers often experience motion sickness, particularly when performing visual tasks such as reading. For example, Jones et al. (2019) found that motion sickness ratings increased with *task* vs. *no-task* during in-vehicle testing on a closed test track facility. Specifically, participants with higher levels of self-reported motion sickness susceptibility produced higher motion sickness ratings during a 20-minute drive. Isu et al. (2014) also demonstrated differences in passenger's subjective rating response between a no-task condition, visual-search task completed using a handheld book, and movie watching from an in-vehicle display mounted in the front row head restraint. Motion sickness severity was highest for the visual-search task, followed by video watching, compared to the no-task condition.

Most studies that have considered task performance and engagement in road vehicle passenger motion sickness response are focused on variations of in-vehicle displays. Variations have included screens that compensate for vehicle pitch motion and relative motion or displays that provide a visual reference with respect to observing a moving image and control of the image on the display augmented (Kato and Kitazaki 2006; Kato and Kitazaki 2008). Kuiper et al. (2018) also evaluated the impact of the positioning of in-vehicle displays on motion sickness. Visual search tasks were performed on display placed directly in front of the passenger at eye height (high) and at the height of the glove compartment (low). The high display position reduced motion sickness response compared with the low display position.

To date, no studies have quantified the effect of on-road motion sickness response on task performance and engagement. The objective of this investigation is to quantify the relationship between passenger motion sickness and non-driving related task performance and engagement during an on-road vehicle exposure.

2.1 Data-Set

This analysis uses data from a vehicle-based platform designed to study motion sickness in passenger vehicles (Jones et al. 2018). Participants completed in-vehicle testing on local urban roads and highways near the University of Michigan.

2.2 Participants

Data were gathered from twenty-two adults (11 women and 11 men) completed all aspects of the within-subject design. Participant age range was 18 to 33 years with a mean of 24 years. Participant body mass index (BMI) range was 19 to 30 kg/m2 with a mean of 23 kg/m2. Participant stature range was 1516 mm to 1933 mm. Prior to data collection, the participants self-reported motion sickness range using categorical descriptors Never, Rarely, Sometimes, and Frequently. Figure 1 shows the distribution of participants by gender and self-reported motion sickness susceptibly. A University of Michigan Institutional Review Board approved this research protocol.

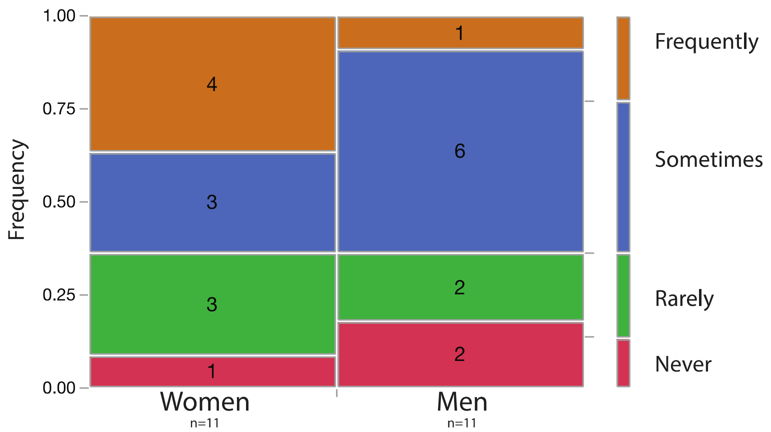

Fig. 1. Mosaic plot of the number of participants who self-report at each frequency level of motion sickness susceptibly stratified by gender.

2.3 Vehicle and Test Conditions

A 4-door, automatic transmission, 6-cylinder, 2007 Honda Accord was used as the test vehicle. The passenger seat was set at its lowest, most rearward position with the seat back angle set to 23 degrees (J826).

On-Road Routes

Testing was conducted on two on-road routes and with and without a task. The urban route was a continuous route on urban and residential roads consisting of a range of vehicle maneuvers (e.g. left and right turns, braking, lane changes and roundabouts). The highway route was designed to evaluate the effect longitudinal acceleration control and higher vehicle speed (~105-112 kph) under conditions of minimal lateral acceleration. Time required to complete each of these on-road routes was approximately 55 minutes.

Task

Two levels of an ecologically relevant task were performed during the in-vehicle scripted route/continuous drive. The no-task condition involved normative passenger behavior and unrestricted gaze. For the task condition a reading task was administered on a handheld mini-iPad tablet. Figure 2 shows a participant seated in the test vehicle for both no-task and task test conditions.

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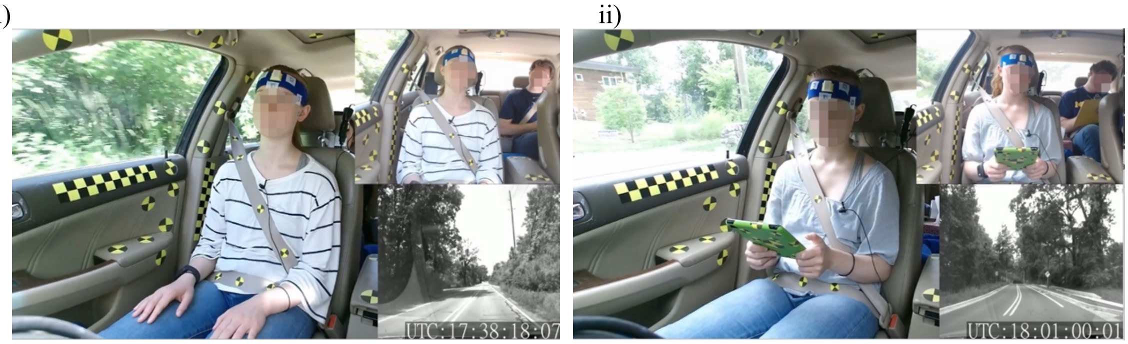

Fig. 2. Participant seated in the test vehicle illustrating two levels of task test condition: i) *no-task*, ii) *task*.

The task was developed based on observed passenger behavior in current vehicles and anticipated behavior in future AVs. Participants were instructed to navigate the pages and attempt to answer a range of questions that involved reading comprehension, visual search, text entry, and pattern recognition, such as local area restaurant reviews, articles about local University sports teams, and maps of the local area (Figure 3). There was no limit to the maximum number of questions that could be answered.

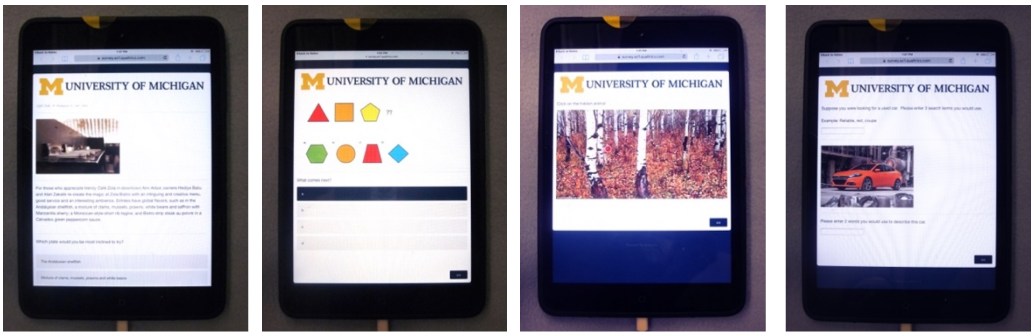

Fig. 3. Example of pages from the iPad task including restaurant reviews, logic puzzles, finding hidden objects and typing words.

A mixed between-within subject design was used. Within gender, participants of similar motion sickness susceptibility were randomly assigned to the two on-road routes. This yielded two participant groups with a similar number of women and men who are approximately equivalent in the distribution of motion sickness susceptibility. Participants completed the task and no-task trials on different days in random sequence.

2.4 In-Vehicle Protocol

During the in-vehicle protocol, a study team driver drove the test vehicle around the scripted route while a second investigator recorded the participant's ratings and sensations associated with motion sickness throughout the drive. Participants rated their motion sickness on a scale from 0 to 10, with 10 the most severe, indicating "Need to stop the vehicle." Motion sickness was quantified by probing the participant for a rating every minute or as they experienced a change in rating and by instructing participants to self-report any sensation they experienced. Each test condition concluded after the route was completed, or when a participant rated their motion sickness as "10" or "Need to stop the vehicle", or when the participant requested to stop the trial, whichever came first.

2.5 Data Analysis

Nonparametric statistics were used to analyze the data given that the data were integer and censored. The maximum motion sickness rating reached during the on-road scripted route was compared across test conditions using signed-rank tests. The 25th percentiles of the distribution of maximum motion sickness ratings for the urban and highway routes were computed and used to classify participants into LOW and HIGH motion sickness response.

Participants controlled the timing of how long each question was displayed for. They also had the choice of whether or not to answer a question. If a participant elected to not provide a response and advance to the next question, they would be asked to confirm their choice to continue without answering. The task would immediately advance on to the next question, after a participant provided an answer and/or non-response. Participant responses to task questions were compared to the answer rubric and classified as: 1) accurate, 2) incorrect, or 3) non-response. Descriptive statistics were computed.

3 Results

3.1 Maximum Motion Sickness Rating

Maximum motion sickness rating was extracted as a scalar representation of each participant's subjective response. Note that maximal ratings did not necessarily correspond with the final rating reported. Across the aggregated data set (i.e. four conditions for a total of 44 individual trials), 25% of the participants did not develop any sensations during the in-vehicle test conditions (i.e. participants reported a rating of 0 or "No Symptoms" throughout), while 5% indicated an illness rating of 10 or "Need to stop the vehicle". Two trials of the urban, *task* test condition ended prior to the intended conclusion of the route due to participant motion sickness.

Figure 4 shows the cumulative distributions of the maximum motion sickness ratings for across all test conditions. The median maximal ratings for the no-task conditions were 2 and 3 for the highway and urban routes, respectively. Task conditions were observed to have higher maximal ratings across the routes. The median maximal ratings were found to be 4 and 7 for the highway and urban, task conditions, respectively. Distribution of maximal ratings between the conditions was evaluated using non-parametric signed rank tests. Population mean ranks of the in-vehicle conditions were found to differ significantly ($\lambda 2 = 10.24$; $p = 0.0166$). Nonparametric comparisons between urban, no-task and task trials ($p = 0.0219$), highway, no-task and urban, task trials ($p = 0.0058$), and highway, task and urban, task trials ($p = 0.0496$) were significant. Further analysis using the Wilcoxon signed-rank test determined that the within-participant difference between the no-task and task conditions was significant for the urban route ($p = 0.0006$), but not for the highway route ($p = 0.0526$).

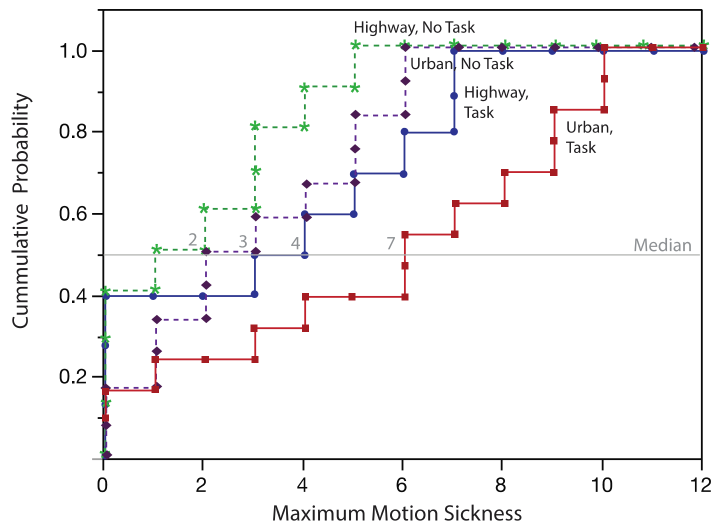

Fig. 4. Cumulative probability distribution of the maximum motion sickness rating across the **urban** and **highway** routes, *no-task* and *task* test conditions.

3.2 Task Performance

Figure 5 illustrates the distribution of task performance during the routes, stratified by two levels of motion sickness response. The number of accurate task responses were observed to decrease with motion sickness response. During the on-road scripted route, the average percentage of accurate task responses was 79% for participants with LOW motion sickness response and 58% for participants with HIGH motion sickness response. The total number of no-responses was also associated with motion sickness response. No-response items were observed approximately two times more frequently for participants with HIGH motion sickness response than for those with LOW motion sickness response (31% versus 12%). The percentage of incorrect task responses was not affected by motion sickness, at 9% for LOW and 11% for HIGH motion sickness responses respectively.

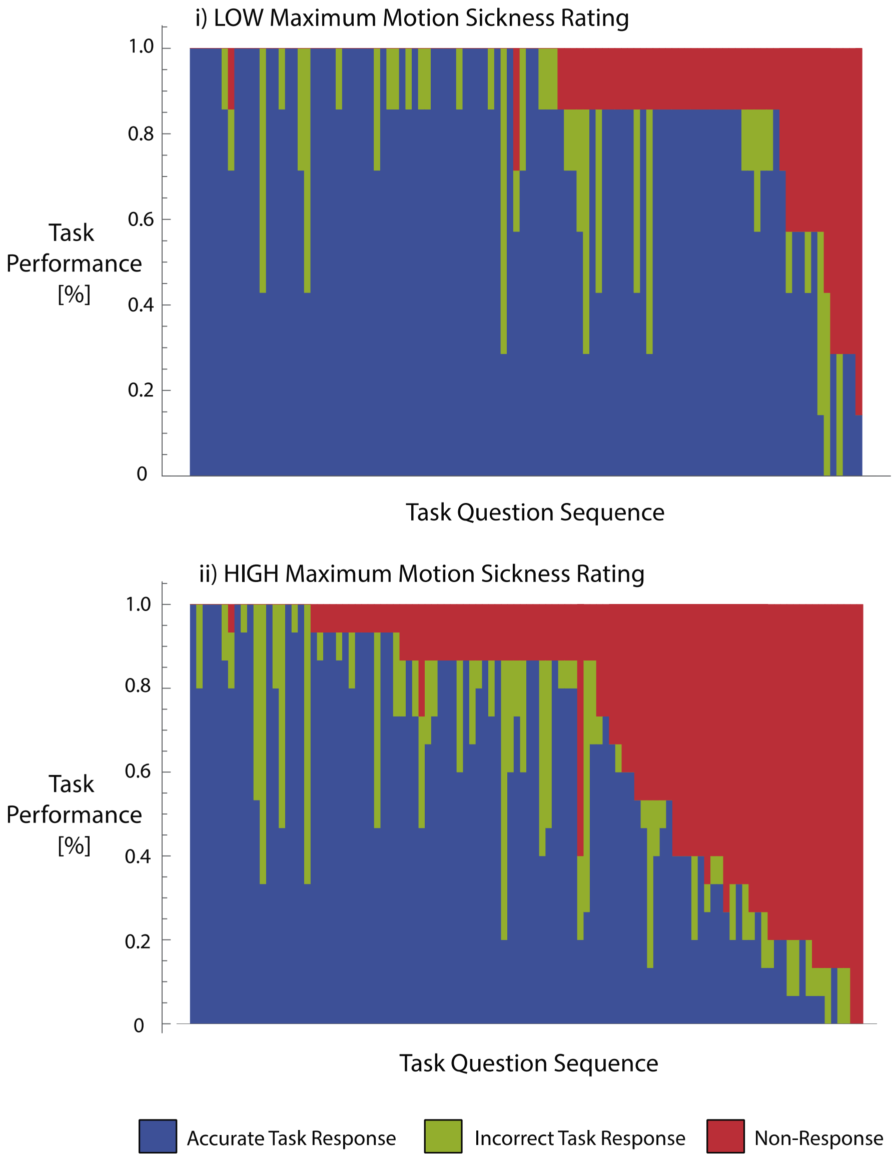

Fig. 5. Distribution of task performance across the levels of passenger motion sickness susceptibility, collapsed across the on-road scripted routes.

4 Discussion

This study is the first to quantify non-driving related task performance and engagement associated with motion sickness response during passenger vehicle operations on-road. The data extends previous research that show motion sickness ratings increase more rapidly when participants are completing visual tasks. Across the dataset, measures of task accuracy and engagement show performance decrements with increasing levels of motion sickness. The data also showed strong differences across individuals, with passengers who experienced a higher level of motion sickness as more likely to have a higher percentage of non-responses.

Future data collection and analyses will investigate the association between the additional performance measures, evaluate differences in task performance between the urban and highway routes, examine changes in task performance with respect to timing progression of motion sickness ratings and sensations, and the comparison of task performance and head kinematic measures. These data will inform the development of a model of etiology of motion sickness consistent with participants' response in road vehicles and enable the design and evaluation of mitigation strategies.

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