Queasy Passengers:
A Testbed for Motion Sickness in Driverless Vehicles

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EXECUTIVE SUMMARY

One of the big promises of self-driving vehicles is the idea that autonomous vehicles will liberate people from driving. In this vision of the future, passengers will scan news reports on phones and tablets, pour over notes and briefings for important meetings, and view videos on their handheld devices. They will reclaim the hours once wasted clinging to a steering wheel.

Unless they end up developing a headache or becoming dizzy, drowsy, or nauseated.

Motion sickness is already a common experience. People can become queasy whether in the family car, on a short roller coaster ride at an amusement park, or in the back of a school bus. One way many people avoid the sensations of motion sickness in cars is by taking the wheel; drivers rarely experience it. Being engaged with the road, and coordinating the human senses with the sensations of road travel, prevents the development of motion sickness symptoms in most people.

Once those drivers become passengers, however, they often feel nauseous or worse, especially if they're reading, using a screen, or performing other visual activities. As a result, automated driving has the potential to greatly increase the incidence of motion sickness among former drivers, according to the authors of a new study funded by Mcity at the University of Michigan, and supported by the U-M Transportation Research Insitute (UMTRI). This poses a significant threat to public acceptance of self-driving vehicles that are designed to turn all of us into passengers.

Jones' interest in motion sickness isn't purely academic. "I get motion sickness all the time, and experienced it growing up, too," she said. "If someone else is driving, I cannot do anything with my time. I am the driver in our family for that reason alone. The goal of our research is to understand the causes of motion sickness so that we can engineer automated vehicles (AVs) to lessen or eliminate the sensations."

The Mcity-funded research defines how to measure the range of sensations experienced by passengers and identifies what type of conditions prompt feelings of motion sickness in vehicles. This work resulted in a testbed that consists of a scripted test drive, instrumentation, and measurement protocols. Applications of the testbed can inform the design of future vehicles that eliminate feelings of queasiness in self-driving vehicles.

THE CHALLENGE

According to the National Institutes of Health, about one in three people are considered susceptible to motion sickness. Despite the high rate in the general population—and a growing amount of discussion about the potential for an even higher rate of illness as vehicle drivers become vehicle passengers—there is very little existing research to help vehicle researchers and developers determine the causes of motion sickness in road vehicles, develop a way to quantify when vehicles provoke illness in passengers, or design solutions to make those passengers comfortable.

Examining the existing research literature, Jones and her multidisciplinary research team found much of it focused on air- and sea-sickness – very different modes of transportation. Even when research was conducted for road vehicles, most findings were based on oscillatory motion or used laboratory motion platforms, which failed to reproduce the range of vehicle motions that occur in real-world scenarios.

Making the need for a test protocol even more important is the fact that vehicle and technology developers are already promoting ideas and filing for patents on potential methods of preventing or mitigating motion sickness for passengers in AVs. But with no repeatable or reliable method of evaluating and comparing these potential remedies, those efforts may not be proven effective or might end up being overlooked.

Several rating scales and questionnaires have been used in past studies to measure motion sickness, with most scales focused on nausea-related symptoms. For example, the appropriately named 11-point Misery Scale requires that participants benchmark themselves against a scale with fixed, explicit levels. During pilot testing for her 2017 study outlined in this white paper, Jones and her team found that (1) participants experienced a wide range of motion-sickness sensations that are not well captured by words related solely to nausea, and (2) participants differed widely in their interpretations of words used to anchor multiple levels of a nausea scale, such that labels do not improve either the administration nor interpretation of the scale. For example, some passengers will feel queasy for a long time but not vomit, while others may have few initial symptoms then suddenly vomit and feel better almost immediately. Other reactions go beyond just a physical response to include sensations such as an indefinite feeling of motion, confusion, mental fogginess or an inability to concentrate. Finally, passengers react in different time frames to differing levels of movement and with varying levels of intensity and pattern of sensations.

DEVELOPMENT OF AN IN-VEHICLE TESTBED

The testbed developed by the Mcity-funded researchers—consisting of a scripted test drive, in-vehicle instrumentation, and measurement protocols—focuses on the need for repeatable and reliable methods to measure how vehicle passengers respond to vehicle motion, including acceleration in different directions, and how passengers respond to those motions when they are focused on a task unrelated to driving.

Prior to the in-vehicle testing, study participants were asked about their history of motion sickness and how likely they thought they were to become ill to ensure that the sampling of participants had susceptibility to motion sickness. Participants also filled out questionnaires asking about their current commutes, the types of roads they drove, whether they felt more or less susceptible to motion sickness during different transportation modes and travel patterns, along with health histories and demographic questions.

For the test drives conducted in 2017, researchers used the Mcity Test Facility, a full-scale outdoor laboratory located on the U-M campus in Ann Arbor that is the first purpose-built proving ground for connected and automated vehicles and technologies. The facility simulates the broad range of complexities vehicles encounter in urban and suburban environments with more than 16 acres of roads and traffic infrastructure.

The in-vehicle testing aimed to create acceleration conditions typical of urban driving and developed based on data from a naturalistic driving study. A 20-minute scripted test drive was developed that consisted of a repeated loop that included a large number of normal driving events that were concentrated into a short period of time, which resulted in approximately 25 braking events, 45 left turns and 30 right turns. The test was conducted at two speeds and two levels of task performance. The low acceleration test condition was at maximum speeds of 10-15 mph, while a moderate acceleration test condition kept the maximum driving speed under 20-25 mph. The activity levels, or tasks, included a normal passenger experience with no task to perform, which allowed the passengers to look wherever they wanted, while maintaining a standard posture with their feet forward on the floor while avoiding use of the headrest and armrests. The second scenario had participants performing a visual task read restaurant reviews or local news stories on a handheld mini-iPad. Task accuracy and response time performance data were gathered as participants answered a range of questions that involve reading comprehension, visual search, text entry, and pattern recognition, based on ecologically relevant content, such as local area restaurant reviews, articles about local University sports teams, and maps of the local area.

In addition to a driver, a second researcher observed and assessed the participant's sensations of motion sickness. In order to record and categorize the responses of participants during the test drive, researchers created a motion sickness rating using a 0-10 scale, with a rating of "0" indicating no motion sickness and "10" indicating "Need to stop the vehicle." This scale was easily understood by the test participants and gave them a way to report the progression of their feelings and responses during the test drives. Participants ratings were recorded every minute or whenever they felt a change. The drive lasted 20 minutes but would end early whenever the passenger rated their motion sickness as "10" or when the passenger asked the driver to stop the testing.

Participants were also asked to describe their feelings and sensations during the test drive in their own words. To help them, researchers showed them a list of common physical responses during motion sickness, such as head sensations, body temperature change, drowsiness, dizziness, mouth sensations, and nausea, as well as task performance-related responses, such as difficulty focusing or concentrating, irritability, and eyestrain.

For each sensation, participants were asked to rate the level of intensity they experienced as mild, moderate or severe.

Participants' motion sickness responses were recorded by asking the test participants to rate their feelings every minute or whenever they felt a change. The drive lasted 20 minutes but would end early whenever the passenger rated their motion sickness as "10" or "Need to stop the vehicle," or when the passenger asked the driver to stop the testing.

During the Mcity tests, sensors and cameras continuously recorded acceleration and geospatial data from the test vehicle, and participant's physiological measures, including sweat, skin temperature and heart rate using a wearable sensor. Head movements – which can increase or reduce sensations of motion sickness. Head orientation was recorded with a headband containing an accelerometer. Optical image cameras and a 3D depth camera were also used to capture facial features, head movements and participants' posture throughout the test drive.

After each test session, researchers took the participants to a recovery area to quantify the decay of their motion sickness response. Rating and physiological measures were taken during the recovery period, and the participants continued to report their sensations every five minutes, until they felt better.

KEY OUTCOMES

This research has led the development of a testbed that consists of a scripted test drive, in-vehicle instrumentation, and measurement protocols that repeatably and reliably, induced and measured motion sickness in a passenger vehicle. Applications of this testbed will result in data required to determine what will and won't help passengers avoid motion sickness in self-driving vehicles.

This study is the first to conduct a large-scale comparison of reading task performance and urban acceleration levels on motion sickness response in a passenger vehicle. Fifty-two adults completed all aspects of the protocol. That included an even split of men and women, with ages ranging from 18 to 78 years old. Each participant was assigned to one of the acceleration levels and was tested with and without the task.

The strongest finding was that reading and interacting with a handheld device results in higher motion sickness ratings. This has important implications for the deployment of AVs as it is anticipated that once freed from the task of driving, passengers will have a much larger behavioral repertoire, including extensive use of handheld device.

Another interesting finding is that young people (age < 60, mean 26 years old) reported higher motion sickness ratings than older people (age > 60, mean 67 years old). Though more research is needed to generalize this finding, it suggests that the young people, who are more likely to adopt the technology, are also at risk of negative outcomes, particularly when they interact with their screens.

This study was also the first to continuously measure the types of sensations associated with motion sickness that passengers experience (a total of 2,774 self-reported sensations were recorded). Sensations were multidimensional and highly variable across individuals indicating that motion sickness is a multi-faceted response that extends beyond nausea. It is likely that the more nuanced sensations associated with motion sickness, which are less severe than nausea (e.g. eye pressure, general discomfort, fatigue), will factor in consumers' willingness to accept and adopt AV technology.

NEXT STEPS

Use cases of the in-vehicle testbed and measurement protocol will enable testing hypotheses, developing solutions, and informing mitigation strategies to the motion-sickness problem.

Data collection for an on-road study using the same in-vehicle testbed is currently underway. The intent of this follow-on study is to quantify the extent to which results from the 2017 concentrated driving exposure on Mcity are applicable to on-road passenger exposures. A scripted route was developed on Ann Arbor local urban roads. The urban route was scaled to the Mcity scripted test drive in that it consisted of the same range of vehicle speed, number and type of vehicle maneuvers (e.g. left and right turns, braking, lane changes and roundabouts), although the time required to complete these maneuvers on-road is approximately 2.5 times as long (~55-60 minutes) as the test drive on Mcity. Data from this study will be analyzed to see how results from the Mcity testbed can scale and apply to on-road conditions.

Data gathered from the in-vehicle testbed, Mcity test drive, and other ongoing research will be used to develop a model of the causes and responses of motion sickness that reflects what happens in road vehicles. Knowledge of passenger motion sickness response is useful to guide AV design and evaluate future mitigation strategies.

About Mcity

Mcity at the University of Michigan is leading the transition to connected and automated vehicles. Home to world-renowned researchers, a one-of-a-kind test facility, and on-road deployments, Mcity brings together industry, government, and academia to improve transportation safety, sustainability, and accessibility for the benefit of society.

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