MotionReader: Visual Acceleration Cues for Alleviating Passenger E-Reader Motion Sickness

Author A. One
Institution1
email1

Author B. Two
Institution2
email2

ABSTRACT

We investigate alleviating the motion sickness experienced by passengers who read using tablet computers or phones, by displaying a visual cue of the acceleration that the passenger undergoes while traveling. This visual cue is meant to eliminate the sensory conflict between the perceived acceleration and the lack of visual indication of the acceleration. The acceleration is measured with sensors integrated in the e-reader. We investigate two visual acceleration cues, the text inertia cue, that displaces the text in the direction opposite to the acceleration, and Gizmo cue, that renders a ball-spring Gizmo adjacent to the text, and that reacts to the acceleration. We have conducted a user study that reveals that the Gizmo cue exacerbates motion sickness symptoms, and that the text inertia cue is effective at alleviating motion sickness symptoms.

ACM Classification Keywords

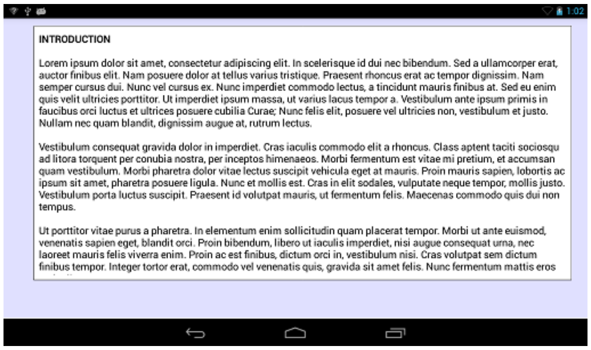
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous.

Author Keywords

e-reader use in vehicles; motion sickness alleviation; acceleration visual cues; user study; text inertia.

INTRODUCTION

Motion sickness is a debilitating condition that prevents many passengers from being productive when they travel by car, bus, airplane, or boat. As mobile e-reader technology has evolved to include internet-connected tablet computers and smartphones making one's office accessible anytime from anywhere, and as many drivers will soon be happily relegated to the role of passengers by driver assistance or even driver supplanting technologies, alleviating motion sickness symptoms suffered by traveling e-reader users has become an important problem. It is generally accepted that one of the root causes of motion sickness is the mismatch between the motion perceived by the user and the lack of visual indication of that motion. The user feels the acceleration but does not see it and has no role in causing it.



INTRODUCTION

Lorem ipsum dolor sit amet, consectetur adipiscing elit. In scelerisque id dui nec bibendum. Sed a ullamcorper erat, auctor finibus elit. Nam posuere dolor at tellus varius tristique. Praesent rhoncus erat ac tempor dignissim. Nam semper cursus dui. Nunc vel cursus ex. Nunc imperdiet commodo lectus, a tincidunt mauris finibus at. Sed eu enim quis velit ultricies porttitor. Ut imperdiet ipsum massa, ut varius lacus tempor a. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Nunc felis elit, posuere vel ultricies non, vestibulum et justo. Nullam nec quam blandit, dignissim augue at, rutrum lectus.

Vestibulum consequat gravida dolor in imperdiet. Cras iaculis commodo elit a rhoncus. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos himenaeos. Morbi fermentum est vitae mi pretium, et accumsan quam vestibulum. Morbi pharetra dolor vitae lectus suscipit vehicula eget at mauris. Proin mauris sapien, lobortis ac ipsum sit amet, pharetra posuere ligula. Nunc et mollis est. Cras in elit sodales, vulputate neque tempor, mollis justo. Vestibulum porta luctus suscipit. Praesent id volutpat mauris, ut fermentum felis. Maecenas commodo quis dui non tempus.

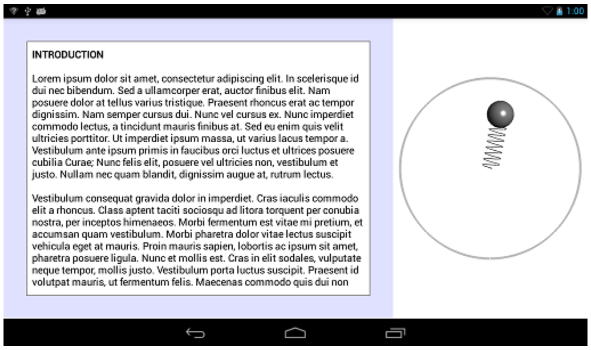
Ut porttitor vitae purus a pharetra. In elementum enim sollicitudin quam placerat tempor. Morbi ut ante euismod, venenatis sapien eget, blandit orci. Proin bibendum, libero ut iaculis imperdiet, nisi augue consequat urna, nec laoreet mauris felis viverra enim. Proin ac est finibus, dictum orci in, vestibulum nisi. Cras volutpat sem dictum finibus tempor. Integer tortor erat, commodo vel venenatis quis, gravida sit amet felis. Nunc fermentum mattis eros

Figure 1: E-reader providing acceleration visual cue by displacing the text oppposite the acceleration vector direction. Here the bus stops so the text shifted closer to the top margin of the e-reader.

In this paper we investigate alleviating motion sickness for those who use e-readers while traveling. The insight is to provide the user with visual cues of the acceleration that they perceive, which will eliminate the sensory mismatch that is thought to cause motion sickness. We propose to integrate the motion sickness alleviation solution with an e-reader application, which can measure accelerations using built-in sensors, and which can display cues of the accelerations measured. We call such a modified e-reader a MotionReader. We have experimented with two modes of displaying the acceleration measured. In the first mode, which we call the Text Inertia mode, the acceleration in the horizontal plane is used to displace the text read by the user in the opposite direction. For example, when the car in which the user travels stops, the text moves forward on the e-reader, i.e. towards the top frame of the computer tablet (Figure 1). In the second mode, which we call the Gizmo mode, the acceleration is displayed by rendering a ball-spring Gizmo on the right side of screen. When the bus turns left, the ball is displaced to the right, deforming the spring (Figure 2).

We conducted a study with 26 participants who rode a bus simultaneously on an urban bus route. The participants were asked to read a text using an e-reader. The participants wore view-limiting hoods that limited their field of view to the e-reader, preventing them from seeing outside the bus, ensuring that any visual cues of the bus acceleration would come from the e-reader, and only from the e-reader. Participants were randomly assigned to one of three conditions: participants in

ACM ISBN .
DOI:



INTRODUCTION

Lorem ipsum dolor sit amet, consectetur adipiscing elit. In scelerisque id dui nec bibendum. Sed a ullamcorper erat, auctor finibus elit. Nam posuere dolor at tellus varius tristique. Praesent rhoncus erat ac tempor dignissim. Nam semper cursus dui. Nunc vel cursus ex. Nunc imperdiet commodo lectus, a tincidunt mauris finibus at. Sed eu enim quis velit ultricies porttitor. Ut imperdiet ipsum massa, ut varius lacus tempor a. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Nunc felis elit, posuere vel ultricies non, vestibulum et justo. Nullam nec quam blandit, dignissim augue at, rutrum lectus.

Vestibulum consequat gravida dolor in imperdiet. Cras iaculis commodo elit a rhoncus. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos himenaeos. Morbi fermentum est vitae mi pretium, et accumsan quam vestibulum. Morbi pharetra dolor vitae lectus suscipit vehicula eget at mauris. Proin mauris sapien, lobortis ac ipsum sit amet, pharetra posuere ligula. Nunc et mollis est. Cras in elit sodales, vulputate neque tempor, mollis justo. Vestibulum porta luctus suscipit. Praesent id volutpat mauris, ut fermentum felis. Maecenas commodo quis dui non

Figure 2: E-reader providing acceleration visual cue through ball-and-spring Gizmo rendered adjacent to the text.

the control condition received a conventional e-reader application; participants in the Text Inertia condition were provided real time visual cues of the acceleration through the displacement of the text; an participants in the Gizmo condition were provided real time cues of the acceleration through the displacement of the ball and the deformation of the spring.

After the bus trip, the participants completed a motion sickness assessment questionnaire (MSAQ) developed from a modified version of the multidimensional questionnaire by Gianaros et al. [6]. The participants also completed a reading comprehension questionnaire about the text they read. The results indicate that the Text Inertia condition alleviates motion sickness symptoms compared to the control condition, i.e. motion sickness average of 0.29 versus 0.34, and that the Gizmo condition accentuates motion sickness symptoms compared to the control condition, i.e. 0.38 versus 0.34. In terms of reading comprehension, the Text Inertia group answered 21% of the questions correctly, the control group answered 18% correct, and the Gizmo group answered 18% correctly.

BACKGROUND

Motion Sickness

Motion sickness is a well-studied phenomenon that affects both operators and passengers of vehicles of various types. It has historically been of principal interest to the aviation community, both among passengers and pilots of aircraft. However, its domain of influence extends to automobiles, boats, and other transport vehicles.

The classical *sensory conflict* theory of motion sickness as pioneered by Reason et al. [18, 17] proposes that the phenomenon is produced by mismatching stimuli between a subject's visual and vestibular systems. During normal human interactions outside of a moving vehicle, motion is typically induced under conscious control, and the subject is visually aware of the motion taking place. The inner ear, where the vestibular sensory organs reside, is capable of correctly detecting most motion produced during such activity. Vehicles produce a wide range of motion that lies outside of the capability of the inner ear to correctly and consistently detect.

Historically, this has been a problem in the aviation domain, where lack of visual cues, typically caused by meteorological conditions, cause the pilot of an aircraft to suffer spatial disorientation (a component of motion sickness). This presents a significant safety risk, and dealing with the phenomenon is a major piece of the modern flight training curriculum [1]. Losing visual cues due to meteorological phenomena, producing a situation where the pilot cannot discern the aircraft's orientation relative to the horizon, was reported to be the cause of 82% of spatial disorientation episodes in a 2003 study by Holmes et al. Other disorienting factors included situations where the view of the outside was sub-optimal, such as at night or while wearing night vision equipment that limits field of view [8].

Figure 3: Participants in the MotionReader experiment. The participants read a text on an e-reader. A cardboard hood restricts each particpant's field of view to their e-reader.

Passengers of land based vehicles are not immune to motion sickness. While riding in a car, both passenger and driver are subject to various acceleration forces produced by the vehicle's motion, but only the driver is consciously inducing those forces (provided of course that the vehicle is under the driver's control). While driving, the driver is exposed to the visual cues that accompany paying attention to the road. Passengers, particularly those engaged in passive tasks, do not have the ability to anticipate vehicular forces and may not even be in a position to visualize the motion of the vehicle, which is categorically similar to the notion of being below the deck of a ship moving at sea [4]. Removal of visual cues presents in the classic scenario of reading a book while inside a moving vehicle, which is one performed frequently by commuters (and often conducted inside buses, trains, and so on). Prior work has sought to answer the question of why drivers are rarely motion sick compared to their passengers. A work by Rolnick and Lubow (1991) [19] suggests that sensory input does not make up the whole picture, but that control is important as well. The study found that control of motion producing conditions, such as being the driver in a car, creates a measure of immunity to motion sickness symptoms.

The type of motion induced by the typical automobile also plays a part in motion sickness. A study by Turner et al. [20] noted that particular low frequency (>0.5Hz) sway and especially the forward-backwards pitch that characterizes bus travel tends to induce motion sickness during bus rides. Seating location on buses is also a factor, with passengers that sit in the back of the bus being subject to more adverse stimuli.

Simulator and Cybersickness

Motion is not required to induce motion sickness symptoms. *Simulator sickness* is observed in subjects who train in flight simulators, or in virtual environments where visual stimulus would indicate motion but where little or no motion is being experienced. This produces similar symptoms to motion sickness and has been termed *simulator sickness* by researchers who study the phenomenon in the context of flight simulators [10] or *cybersickness* in the context of video games, interactive media, and virtual reality [2]. While simulator sickness and cybersickness differ from motion sickness in the classical sense, they share many symptoms in common.

Due to the wide adoption of smartphones and other mobile devices, it is anticipated that a larger percentage of users will be exposing themselves to motion sickness-inducing stimuli *as part of their passenger experience*. Market research conducted by PayPal, Inc. in 2016 showed that 78% of U.S.-based consumers used their smartphones for gaming, and that more than half read books on their mobile devices [9]. With the integration of virtual reality media into the smartphone market, this trend will invariably continue.

Towards Autonomous Vehicles

In a completely self-driving automobile, the driver is expected to be engaged in passive or monitoring tasks. However, the path to total autonomy will be required to cross the domain of so called *dual-mode* vehicles, which several manufacturers intend to offer within the next five years [3]. This particular mode of operation, which features both automatic and manual modes of driving, will require the driver to transition *between* being an active and passive participant. Diels et al. use the term *self-driving carsickness* to characterize the type of motion sickness produced in this scenario [4]. The ergonomic design of more modern vehicles also plays a part in their potential to induce motion sickness, in particular seating arrangements of an exotic type. Proposed designs that include flexible seating arrangements such as rearward or side-facing seats have the strong potential to remove necessary visual stimuli that alleviate symptoms unless user interface solutions are presented to correct this [3, 4].

Risk Factors in Autonomous Vehicles

The above works provides several indicators that autonomous vehicles present a higher risk to drivers of autonomous vehicles than traditional ones. To summarize, they include:

- Passive and monitoring tasks, along with the transition between active and passive control of the vehicle remove, the driver's visual attention to the motion of the vehicle and interrupt visual flow.
- The driver no longer prompts the motion of the vehicle [19].
- Electronic device usage may compound the problem, since games and other media can produce motion sickness-inducing stimulus [2].
- Seating arrangements on autonomous vehicles may be suboptimal for viewing the movement of the vehicle, and may place occupants in a position where motion is experienced in a way that compounds the problem [4, 20].

Methods For Assessment

Several methods have been developed to assess motion sickness in order to gauge severity in clinical and research settings. For decades, the U.S. Military has used what is known as the *Pensacola Motion Sickness Questionnaire* developed in 1968 to assess levels of motion sickness based on subjects' self-reporting of symptoms in a military aviation setting [7]. Later, the Simulator Sickness Questionnaire (SSQ) was developed by Kennedy et al. in 1993 to gauge symptoms that arose from participation in flight simulator training [11]. Various other variations exist, including a multi-dimensional questionnaire by Gianaros et al. to assess motion sickness based on multiple distinct factors [6].

These methods are easy to administer as the user is only required to fill out a short questionnaire, usually involving some self-reporting on severity of specific symptoms. However, the self-reporting aspect means that these data points are subjective.

Remedies for Motion Sickness

Remedies for motion sickness have been proposed to help reduce the effect of negative stimuli, or that provide sensory input to reduce symptoms and help to eliminate the problem.

One solution involves the use of head-mounted displays (HMDs), which are frequently used in military aviation but also in other contexts. Krueger (2011) studied the use of a head-mounted artificial horizon display in motion intolerant individuals, many of whom reported it as "quite helpful" in alleviating their symptoms [12]. However, it requires the user to wear the HMD and ancillary equipment, and was targeted at users with a particular pathology. When tested on U.S. Air Force pilots, results were not as positive. Participants sometimes stated that it was a distraction [16].

Other works have attempted to supplement motion sickness-inducing visuals with additional visual stimuli that could alleviate symptoms. Duh et al. (2001) conducted an experiment in which participants were exposed to visuals involving low frequency rotation that induced spatial disorientation, which is an important component of motion sickness. Participants who were shown a visual background independent of the motion (an "Independent Visual Background," or IVB) experienced less disorientation and accordingly less postural instability [5]. The experiment was limited to the type of visualization that could be presented in a setting where participants were stationary, and where postural instability was used as the primary indicator of symptoms.

Driving simulators, flight simulators, and various virtual reality techniques have historically also been used in work that attempts to address motion and simulator sickness problems. Lin et al. (2004) placed participants in a driving simulator that drives around inside a virtual environment [13]. Participants who were shown a virtual avatar that provided turn and translation cues to predict the motion of the simulated car reported statistically significantly less symptoms on a revised version of the the Kennedy simulator sickness questionnaire (SSQ) than users who were not given any visual cues. As with the IVB experiment, this was limited to a driving simulator and did not involve motion characteristic of driving a car.

Targeting the user interface of autonomous vehicles to present vehicular motion cues is strongly suggested [4], however the interfaces of e-readers and tablets are a prime target for intervention as well. An experiment by Miksh et al. (2016) presented users of an e-reader application with front-facing camera footage of a car's motion as the background to the reading material. [15] Users reported, on average, less discomfort while reading in a car using this method than with the traditional method. However, the provided footage was presented from a single angle (front facing) and did not address issues with alternate seating arrangements or cases where users might prefer to hold a device on their lap or at an odd angle.

Recently, it was shown in an exciting new work that Virtual Reality HMDs can potentially be used to provide helpful visual cues to passengers in cars as a motion sickness remedy while using the Kennedy SSQ as a measure of symptom severity. [14] Remedy effectiveness varied by user, with various combinations of visual cues presented in the VR headset (tracking with car motion, peripheral motion cues, rotation compensation, etc). Users reported a higher comfort level with some remedies, but the reported comfort level varied by user. However, the study of VR-based remedies in an actual moving vehicle is compelling.

MOTIONREADER OVERVIEW

A useful method for alleviating motion sickness symptoms should seek to address near-term issues faced by drivers of autonomous vehicles as well as passengers who might choose to use an e-reader application on a smartphone or tablet as a passive task during travel. Because the tablet is the focus of the user's attention while riding, we target the tablet's user interface with an application called *MotionReader*, an e-reader that includes a visualization that provides a visual indicator of the vehicle's acceleration.

Hardware

We developed our MotionReader with minimal hardware requirements. One such requirement is the presence of a 3-axis accelerometer, which is met even by inexpensive, previous generation tablets such as Amazon's Kindle Fire tablet, which we use in the experiments presented in this paper.

Visual acceleration cues

The MotionReader provides visual cues of the acceleration in one of two modes:

- **Text Inertia**: A reading pane which moves, along with all of its contained text, opposite the direction of acceleration from a top-down perspective (Figure 1). This also stops at a predetermined maximum, preventing the text from leaving the screen.
- **Gizmo**: A ball connected to a spring (Figure 2), which stretches out opposite the direction of acceleration from a top-down perspective, and stops at a predetermined maximum elongation. The ball-and-spring is rendered orthographically in 3D.

Users were able to scroll through the text in the usual way, by dragging the text in the desired scroll direction. A standard scroll bar was provided to assist as an indicator of where in the text the user was reading.

Acceleration Processing

The tablet's internal 3-axis accelerometer provides raw acceleration data via the Android API. This required pre-processing before it could be used as part of the visualization, as raw accelerometer data contains noise, and as the actual vehicle acceleration is confounded by the gravitational acceleration.

Filtering

A basic low-pass filter consisting of a simple moving average (SMA) computed at 30 frames per second was used to deal with noise. Selecting a larger filter size produced a more sluggish but less noisy accelerometer response. An adjustable filter size allowed us to calibrate MotionReader in pilot runs described below.

Gravity Calibration

Because the direction of acceleration was rendered in both of our experimental configurations from a top-down perspective, the direction of real gravity was required before performing any calculations leading up to the rendering step. While newer versions of tablets and phones are capable of performing this step as a function of their API, our minimal hardware requirements prevented us from relying on this functionality. We developed two methods of determining gravity direction:

- **User Calibration:** The user performs a long press on the surface of the tablet, triggering the application to re-orient the MotionReader along the currently detected gravity vector.
- **Auto-Calibration:** Real gravity direction is continually recomputed using a weighted moving average function with a large window, under the assumption that the only long lasting acceleration is that due to gravity.

Acceleration Projection

Once the gravitational acceleration g is known, one can remove it from the measured acceleration r to recover the actual vehicle acceleration h. We compute the component a of r along g and then we subtract a from r to obtain h, as follows:

$$\hat{\boldsymbol{g}} = \frac{\boldsymbol{g}}{||\boldsymbol{g}||}$$
$$a = \hat{\boldsymbol{g}}(\boldsymbol{r} \cdot \hat{\boldsymbol{g}})$$
$$\boldsymbol{h} = \boldsymbol{r} - \boldsymbol{a}$$

Finally, h is projected to the e-reader display plane by dropping its z coordinate (Figure 4). Our visual acceleration cue ignores any vertical acceleration component. In other words, our

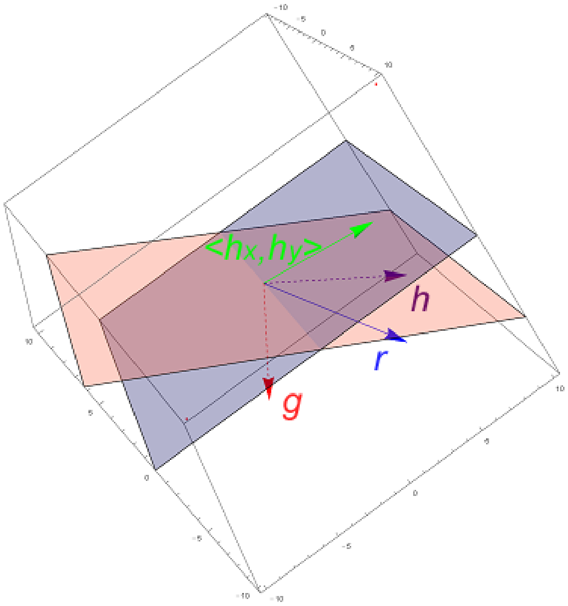


Figure 4: Mapping vehicle acceleration to the e-reader display plane. The measured acceleration r is decomposed into components parallel and perpendicular to the pre-calibrated gravitational acceleration g. The perpendicular component h is projected onto the e-reader display plane (blue) by dropping the z coordinate.

acceleration visualization is 2D, it only takes into account the acceleration components in the horizontal plane.

MotionReader Behavior

The appearance of the Gizmo visualization is shown in Figure 2. As the vehicle decelerates, the ball moves forward stretching the spring. Forward accelerations cause it to move backwards and lateral accelerations produce side to side movement. The amount of deformation illustrates the acceleration within a predetermined range along the plane horizontal to gravity. For the maximum acceleration, the ball touches the gray circle, and larger accelerations are clamped.

The Text Inertia remedy behaves similarly to the gizmo, but in this case it is the text portion of the reader that moves (Figure 1). During the experiment, we configured the movement of the text such that it would not exceed the boundaries of the tablet's screen.

EXPERIMENT

We investigated the MotionReader's motion sickness alleviation potential in an experiment where participants riding a bus were asked to use the MotionReader in one of three conditions. The experiment was approved by our institutional review board.

MotionReader parameter calibration

Before the actual experiment, we estimated reasonable values for the various MotionReader parameters in pilot runs. A group of four participants used the MotionReader with various parameter settings. The participants wore field of view limiting hoods, and the pilot runs were conducted on an urban bus route similar to the one that was going to be used during the actual experiment.

Experienced MS	*In Car*	*In Bus*	*Reading Worse*
23	15	16	17

Table 1: Motion sickness history

The pilot runs converged on a $0.1g$ (i.e. approximately $1m/s^2$) minimum acceleration threshold, which avoids vibration of the text and of the ball due to small amplitude acceleration noise. The maximum acceleration threshold selected was $0.4g$, which matched the start/stop and left/right accelerations of the bus on the route. When the maximum acceleration threshold is exceeded, the text stays to the maximum displacement position, on screen, until the acceleration decreases below the threshold and the text begins to move back to the neutral position. Similarly, the spring stays at maximum elongation while the acceleration exceeds the maximum threshold.

The pilot runs also revealed that the gravity auto-calibration mode would confuse extended accelerations, as those experienced, for example, during turns that lasted several seconds, with gravity. We felt that the advantage of gravity auto-calibration, which is to allow the participant to change the position of the MotionReader during reading, does not warrant the risk of incorrect acceleration display, so for the actual experiment we settled on using the user-triggered calibration mode.

Finally, the pilot runs also determined the size of the filtering window to 12 frames, which provided a good compromise between the noisiness and the inertia of the acceleration visualization.

Randomized Controlled Trial

Participants

We recruited 26 participants by advertising in large enrollment courses in our university department. The participant age range was 18-42 years with a mean age of 25. 13 participants were male and 19 participants were female. Before the experiment started, we asked participants about their previous experience with motion sickness. The experiment took about one hour. At the end of the experiment, the participants were compensated with $20 gift cards. Participants were initially asked if they had previously experienced motion sickness, if they had done so in a car as a passenger, in a bus as a passenger, and if reading made symptoms worse. Results are summarized in Table 1.

Motion Sickness Questionnaire

For the experiment, we selected and modified a multi-dimensional motion sickness assessment questionnaire (MSAQ) developed by Gianaros et al. which measures motion sickness symptoms along multiple dimensions: Gastrointestinal, Central, Peripheral and Sopic[6]. We modified this questionnaire by removing the "clammy/cold sweat" question due to what we expected would be confusion over the difference between that and the "sweaty" question in the Peripheral category.

Methods

Before the experiment, the participants completed a previous motion sickness experience questionnaire and a demographics questionnaire, they were briefed about the experiment, they were shown how to calibrate the device, and they were shown how to put on the field of view limiting hood of the type used in instrument pilot training [1]. The hood was designed to block pilots' vision of the outside of the cockpit to ensure focus on the instruments during training. In our case, the hood accomplished the important goal of preventing a participant from seeing outside the bus, ensuring that any visualization of the acceleration was provided by the participant's MotionReader instead of peripheral visual flow. The type of view limiting device used consists of a commonly available cardboard hood held in place with an elastic headband.

The briefing emphasized that a participant should stop reading and remove their hood as soon as they perceive considerable motion sickness symptoms, and way before motion sickness symptoms would become severe enough to risk inducing emesis. Then each participant was given a Kindle fire tablet running the MotionReader application in one of three configurations: the Text Inertia condition, which visualizes the acceleration by displacing the text, the gizmo condition, which visualizes the acceleration by displacing the ball and deforming the spring, and the control condition which does not visualize the acceleration in any way. The same text was used in all three conditions, a text derived from a nonfiction history work written at the reading level of students in 10th grade at U.S. high schools.

Then the participants were loaded onto a bus. While the bus was parked, the experimenters made sure all participants put on their view-limiting hood and that they had calibrated their MotionReader. Participants were reminded to discontinue the experiment if they experience significant motion sickness symptoms. The experimenters had medical grade emesis bags on hand to distribute to participants, should they need them. All participants faced forward, i.e. in the direction of motion. The assignment of participants to bus seats was random. The participants began reading and the bus proceeded on the predetermined route that would take approximately 20 minutes. Four participants felt motion sick to the point that they decided to discontinue the experiment. They were handed motion sickness bags, but none of the four ended up needing them.

Results and Discussion

After the experiment, the participants completed two questionnaires, the MSAQ, which gauged the motion sickness symptoms experienced during the bus ride, and an exit quiz, which asked participants about their perception of the visual conditions (if any) and contained 11 questions which tested their understanding of the text read.

The MSAQ contained 15 questions requiring participants to gauge symptoms on a scale of 1 (nothing) to 9 (severe). The MSAQ is scored by summing the responses in each category and then dividing by the total number of points in that category. A higher score indicates a higher level of overall motion sickness. The total is the sum of all questions divided by the total points in the entire questionnaire. The average motion sickness scores and standard deviations across all categories are summarized in 2. From the four participants who experienced motion sickness symptoms severe enough to stop the experiment early, 1 was from the Control group and 3 were from the Gizmo group. Although the group sizes and the average sizes are too small to infer statistical significance, the Text Inertia mode of displaying acceleration seems to alleviate motion sickness symptoms, and the Gizmo mode seems to make it worse.

Condition	*Total*	*GI*	*Central*	*Peripheral*	*Sopic*
Control	**0.34**	0.32	0.34	0.25	0.43
Gizmo	**0.38**	0.39	0.38	0.21	0.50
Text	**0.29**	0.28	0.30	0.20	0.37
sdText	**0.13**	0.19	0.15	0.11	0.17
sdGizmo	**0.19**	0.29	0.20	0.17	0.22
sdControl	**0.18**	0.24	0.13	0.19	0.27

Table 2: MSAQ Scores

	Sick in Car or Bus	*Reading Worse*
Yes	0.41	0.36
No	0.29	0.30

Table 3: Motion sickness history vs. MSAQ scores

Possible explanations of the Gizmo's accentuation of motion sickness symptoms are: The Gizmo visualization reduces the amount of space available to render the text, thereby reducing the user's field of view; the moving Gizmo animation captures the user's attention, distracting them from reading; the Gizmo animation latency, caused by the acceleration filtering, is obvious and motion sickness inducing, akin to the effects of latency in head-mounted display virtual reality applications. The Text Inertia visualization does not reduce the field of view, it does not distract away from the words being read, and latency is less noticeable and more acceptable. Furthermore, in the Text Inertia mode the text is not rigidly anchored to the user, but rather to the world, as if the user tries to read a billboard on the side of the road. In the Text Inertia condition, the user does focus on an element of the world, which is a known way of recovering from motion sickness, as motion sick passengers find relief by looking at the world through the vehicle's window. In the Gizmo condition, the text is anchored to the user, so the user never stops focusing on the visuals that are devoid of acceleration cues.

The questionnaire about the visualization revealed that 5 out of the 7 participants in the Text Inertia group did not notice any visualization, and one participant stated that the Text Inertia condition helped them read, which is encouraging since the intervention is supposed to alleviate motion sickness symptoms in an inconspicuous way, without siphoning cognitive effort from reading. In addition, those who reported that they had been motion sick in a car or bus, and those who reported that reading made their motion sickness worse, had higher average MSAQ scores than those who did not (Table 3).

The reading comprehension questionnaire had 11 questions about names, dates, and specific facts contained in the text. The average number of questions answered correctly for the Text Inertia, Control, and Gizmo groups of participants were 2.33, 2, and 2 (respectively).

CONCLUSIONS AND FUTURE WORK

We have investigated the potential motion sickness alleviation benefits of providing the user of an e-reader with visual cues of the acceleration that the user undergoes while traveling in a vehicle. One visualization illustrates the acceleration by rendering the text with inertia, and one by rendering a ball and spring gizmo adjacent to the text.

Plans for future work include overcoming some of the limitations of the present study. One limitation pertains to the manual gravity calibration procedure. One solution is to prevent the user from modifying the MotionReader position during the experiment, for example by placing the MotionReader on a tray-table attached to the bus seat in front of the participant. Another possible solution is to use state of the art tablet computers that provide an API function for determining the gravity vector. This will allow for the user to modify the position of the tablet during lecture at will, without having to worry about re-calibrating. Another limitation of the current work is the limited size of the study. More participants are needed to ascertain statistical significance of any of the advantages measured, and to correlate effective intervention parameter values to the motion sickness sensitivity profile of individual participants. Furthermore, in this work we relied on a 2D visualization of the acceleration, discounting any vertical acceleration. Whereas this is a reasonable assumption in the case of a land-based vehicle such as a car or bus, airplanes and boats require a more complex 3D visualization of gravity. Out of plane displacement could be visualized with shadows that indicate the distance between the text and a virtual display plane.

Another direction of future work is to investigate additional ways of conveying acceleration cues visually. The idea of a virtual window, simulated through augmented reality is worth exploring. Previous work [14] did use the video feed captured from a dash camera as a background to the text in an e-reader application, with the limitation that the visual cue of the acceleration is not correlated to the tablet position. The interior cabins of recent cruise ships are outfitted with large TV's that can show a camera feed of the sea and horizon, simulating the missing porthole, with known motion sickness alleviation benefits (addressing what is perhaps one of the oldest known sources of motion sickness). However, in the e-reader application context, the goal is to interfere with the application payload, e.g. the text to be read, as little as possible, which requires distilling the representation of the real world to a minimalist form while preserving the motion sickness alleviation benefits.

Finally, our current work targets reading, which, although very common, it is not the only application frequently used on tablets and phones. Video and image viewing, text messaging, web browsing, social media interactions, and even computer gaming are activities that would benefit from specifically optimized motion sickness alleviation interventions, allowing the members of our society to reclaim the productive use of millions of hours wasted commuting.

ACKNOWLEDGMENTS

Withheld for double-blind review.

REFERENCES

1. Federal Aviation Administration. 2017. Instrument Flying Handbook (FAA-H-8083-15B). (2017).
2. Simon Davis, Keith Nesbitt, and Eugene Nalivaiko. 2014. A Systematic Review of Cybersickness. In *IE2014: Proceedings of the 2014 Conference on Interactive Entertainment*. ACM, 1–9.
3. Cyriel Diels. 2014. Will Autonomous Vehicles Make Us Sick?. In *Ergonomics & Human Factors*.
4. Cyriel Diels and Jelte E. Bos. 2015. User Interface Considerations to Prevent Self-Driving Carsickness. In *AutomotiveUI '15: Adjunct Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. 14–19.
5. Henry Been-Lirn Duh, Donald E. Parker, and Thomas A. Furness. 2001. An Independent Visual Background Reduced Balance Disturbance Envoked by Visual Scene Motion: Implication for Alleviating Simulator Sickness. In *Proceedings of the ACM CHI 2001 Human Factors in Computing Systems Conference*. ACM, 85–89.
6. Peter J. Gianaros and others. 2001. A Questionnaire for the Assessment of the Multiple Dimensions of Motion Sickness. *Aviation, Space, and Environmental Medicine* 71, 2 (feb 2001), 115–119.
7. A. Graybiel and others. 1968. Diagnostic Criteria For Grading The Severity Of Acute Motion Sickness. *Aerospace Medicine* 39, 5 (may 1968), 453–455.
8. Sharon R. Holmes and others. 2003. Survey of Spatial Disorientation in Military Pilots and Navigators. *Aviation, Space, and Environmental Medicine* 74, 9 (sep 2003), 957–965.
9. PayPal Inc. 2016. *Digital Media Consumers*. Technical Report.
10. David M. Johnson. 2005. *Introduction to and Review of Simulator Sickness Research*. Technical Report. U.S. Army Research Institute for the Behavioral and Social Sciences, U.S. Army Reearch Institute for the Behavioral and Social Sciences, 2511 Jefferson Davis Highway, Arlington, VA 22202-3926.

11. Robert S. Kennedy, Norman E. Lane, Kevin S. Berbaum, and Michael G. Lilienthal. 1993. Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. *The International Journal of Aviation Psychology* 3 (1993), 203–220. Issue 3.
12. Wesley W.O. Krueger. 2011. Controlling Motion Sickness and Spatial Disorientation and Enhancing Vestibular Rehabilitation With a User-Worn See-Through Display. *The Laryngoscope* 121 (2011), S17–S35.
13. James J.W. Lin, Albi-Rached Habib, and Michael Lahav. 2004. Virtual Guiding Avatar: An Effective Procedure to Reduce Simulator Sickness in Virtual Environments. In *Proceedings of the ACM CHI 2004 Human Factors in Computing Systems Conference*. 719–726.
14. M. McGill and others. 2017. I Am The Passenger: How Visual Motion Cues Can Influence Sickness For In-Car VR. In *CHI Conference on Human Factors in Computing Systems*.
15. Markus Miksch, Martin Steiner, Michael Miksh, and Alexander Meschtscherjakov. 2016. Motion Sickness Prevention System (MSPS): Reading Between the Lines. In *Adjunct Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. 147–152.
16. Fred H. Previc, Nathan A. Dillon, Rick H. Evans, Ryan Maresh, William R. Ercoline, and Joseph Fischer. 2011. *The Effects of a Novel Head-Mounted Symbology on Spatial Disorientation and Flight Performance in U.S. Air Force Pilots*. Technical Report. Air Force Research Laboratory, 711th Human Performance Wing, School of Aerospace Medicine, Aeromedical Research Department, 2510 Fifth St. Wright-Patterson AFB, OH 45433-7913.
17. J.T. Reason. 1978. Motion Sickness Adaptation: A Neural Mismatch Model. *Journal of the Royal Society of Medicine* 71 (1978), 819–829.
18. J.T. Reason and J.J. Brand. 1975. *Motion Sickness*. Academic Press.
19. Arnon Rolnick and R.E. Lubow. 1991. Why is the Driver Rarely Motion Sick? The Role of Controllability in Motion Sickness. 34, 7 (1991), 867–879. `DOI:` `http://dx.doi.org/10.1080/00140139108964831`
20. Mark Turner and Michael J. Griffin. 1999. Motion Sickness in Public Road Transport: The Effect of Driver, Route, and Vehicle. *Ergonomics* 34, 12 (dec 1999), 1646–1664.