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► **To cite this version:**

Alexander Meschtscherjakov, Sebastian Strumegger, Sandra Trösterer. Bubble Margin: Motion Sickness Prevention While Reading on Smartphones in Vehicles. 17th IFIP Conference on Human-Computer Interaction (INTERACT), Sep 2019, Paphos, Cyprus. pp.660-677, 10.1007/978-3-030-29384-0_39. hal-02544623

HAL Id: hal-02544623

<https://inria.hal.science/hal-02544623>

Submitted on 16 Apr 2020

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Bubble Margin: Motion Sickness Prevention While Reading on Smartphones in Vehicles

Alexander Meschtscherjakov¹[0000-0001-8116-4522], Sebastian Strumegger², and Sandra Trösterer¹

¹ Center for Human-Computer Interaction, University of Salzburg, Salzburg, Austria
{alexander.meschtscherjakov, sandra.troesterer}@sbg.ac.at

<https://hci.sbg.ac.at/>

² University of Salzburg, Salzburg, Austria
s.strumegger@gmx.at

Abstract. The shift towards autonomous driving will allow people to read and work while riding in such a vehicle. Some people suffer from motion sickness while being engaged in these activities in a moving vehicle since the signals of the visual and vestibular systems of the human body are mismatched. One approach to mitigate motion sickness is to provide visual cues for the affected person. We present Bubble Margin, a smartphone application to reduce motion sickness while reading in a moving vehicle. It is built as a stand-alone, semi-transparent overlay application that visualizes motion cues in form of bubbles at the margins of a smartphone while other applications may be used in the remaining area. Forces to move these bubbles are taken from smartphone sensors. An initial within-subject design study (N=10) with participants performing a reading task in a real driving scenario showed mitigating effects on motion sickness symptoms.

Keywords: Motion Sickness · Nausea · Smartphone Application · Peripheral Vision.

1 Introduction

People have always had an urge to put their free time to good use while traveling and modern technology has introduced various ways for us to entertain and educate ourselves while being on the move. For example, one third of Canadian college students choose to use their smartphones when riding on buses [15]. However, several people suffer from motion sickness symptoms such as nausea, sweating, and dizziness when using their smartphones in moving vehicles. Susceptibility to motion sickness varies depending on multiple factors such as age, gender, vestibular diseases and the type of transportation and movement (e.g., [3, 7, 12, 18, 24]).

The future of automated cars is likely to bring about an even greater amount of people being exposed to activities inducing motion sickness. Recent studies by Sivak and Schoettle [27] have shown, for example, that 37% of adult U.S. citizen

passengers in fully self-driving vehicles are expected to be involved in activities that increase the frequency and severity of motion sickness, such as reading or watching movies. According to their estimations, about 6-12% of U.S. citizen passengers will experience moderate or severe motion sickness at some time.

The prevailing theory suggests that in many cases motion sickness is caused by a sensory conflict between the visual and vestibular systems of the human body, whenever there is a mismatch between the anticipated and the actual signal [25]. This is often the case when passengers are riding in a vehicle, especially when the roads are curvy. Thereby, motion sickness symptoms occur especially on low frequency motion (<1 Hz) and seem to peak around 0.2 Hz [14]. It was shown by Bos [5] that adding high frequency motion in form of non-sickening vibration can reduce the sickening effect of low frequency motions.

If a passenger sitting in a bus looks out the window and fixates a point, e.g., a road sign, the vestibular and visual systems cooperate in order to stabilize the eyes as the bus turns. However, this vestibulo-ocular reflex is repressed by the visual pursuit mechanism if the passenger is reading a newspaper [6]. As a result the passenger's eyes do not follow the bus' motion, creating a sensory conflict. If the passenger's eyes are not focused on the road ahead the linear acceleration and deceleration of the vehicle can cause motion sickness [4].

There are several fundamentally different approaches when it comes to preventing or mitigating motion sickness. *Pharmalogical* countermeasures have been proven to be effective, but the developed drugs can provoke unwanted side effects and oral administration must be planned well in advance for the body to absorb the necessary substances in time [12]. Those drawbacks may be acceptable for long ship cruises but they are not for everyday car or bus drives.

Habituation has proven to be very effective against motion sickness by the military, as jet pilots cannot be allowed to deal with undesirable side effects. Cowings and Toscano [8] have shown that habituation to the repeated stimulus is superior to pharmalogical treatment. While being very effective, this method is also very time-consuming and the training can last several weeks [12].

Orientation is another element having an influence on motion sickness. Sailors, for example, have long used the method of fixating their vision on the horizon as a reference point in order to reduce the sensory conflict of the visual and vestibular systems [26]. In the automotive domain it is known looking through the windshield onto the road might mitigate motion sickness symptoms [28].

Another key factor in preventing motion sickness closely related to orientation is *anticipation*. Drivers, for example, tend to get less sick than passengers since in addition to them having a clear view on the road, they are in control and therefore can anticipate the incoming motion [9]. The common belief that backwards seating passengers are more likely to suffer from motion sickness symptoms lines up with the theory that an awareness of the road ahead mitigate the symptoms, as shown by Griffin and Turner [28].

Recently, there have been several approaches to use technology to mitigate motion sickness symptoms. Most of them use visual stimuli to help with ori-

entation and anticipation, such as the MotionReader [16] the Motion Sickness Prevention System (MSPS) [23], or the Peripheral Visual Feedforward System (PVFS) [19]. Our approach is to utilize visual feedback on linear acceleration forces in real-time for people riding in a vehicle to fight motion sickness. Thereby visual stimuli are presented at the margin of a smartphone display. Passengers are perceiving the stimuli in their peripheral view while interacting or reading at the remaining area of the smartphone.

Motivated by these thoughts we are presenting Bubble Margin, an Android application designed to mitigate motion sickness symptoms by providing visual feedback on linear acceleration forces. Bubble Margin works as a stand-alone application. It visualises moving objects within a semitransparent frame on a smartphone screen. By choosing a border design, we believe to have created a non-disruptive smartphone experience while providing visual motion cues. The effect of our interface was tested in an initial within-subjects study (N=10), assessing motion sickness severity before and after test drives in a real driving scenario. Participants were further asked to make changes to the design (e.g., border size, number of bubbles, color) in order to gather information about user preferences.

The approach to use visual stimuli in that way to mitigate motion sickness is not new, as we have outlined above. The novelty lies in that fact, that our approach does not need any additional hardware and can run as an overlay on any application running on a smartphone.

2 Related Work

Visual information about upcoming car movements raises situation awareness and as a result can mitigate the effects of motion sickness, as shown by the Peripheral Visual Feedforward System (PVFS) of Karjanto *et al.* [19]. The PVFS used LED lights next to two displays to inform video-watching study participants about the next turn. The undeniable benefit of this system is that the displayed visual cue does not affect the viewed content, since LED lights are placed outside of the screen. However, it requires additional hardware to be installed, as well as information about upcoming movements.

Apart from visual feedback cues, Yusof *et al.* [29] have created a haptic feedback device consisting of several vibrating mini motors. They have increased passenger's situation awareness about upcoming movements by emitting vibrations to the forearms. A preliminary study has shown promising results regarding the connection of motion sickness and situation awareness. Apart from navigation information, the challenge with providing anticipatory information is, that it requires accurate estimation of future vehicle movements. One approach is to use GPS data, which has been shown to be rather inaccurate in smartphone GPS sensors [2].

Thinking about a future of fully automated cars and the constantly improving technologies in the virtual reality sector, passengers are likely to be using VR Head Mounted Displays (HMDs) while driving. However, the limited visual

information about motion is destined to create a sensory conflict while driving. McGill *et al.* [22] have explored this possibility by conducting a study with participants wearing VR HMDs, establishing a baseline for future work. It was shown that there is no universal presentation of motion on the display that eases motion sickness. Different participants had different preferences and the wrong presentation could actually even have a negative effect on motion sickness symptoms.

Hock *et al.* [17] have present CarVR an HMD that maps vehicular movements to the visual information presented within a virtual reality world. This allows users to feel the kinesthetic forces produced while riding during the VR experience. The car's acceleration was taken into consideration for rendering the virtual environment to mitigate simulator sickness. They have shown that simulator sickness is reduced compared to a stationary VR experiences.

In HCI research, only little work has been published picking up the context of smartphone or tablet displays in combination with motion sickness. Hanau and Popescu [16] studied bus passengers using e-readers by presenting their approach MotionReader. They have developed two interfaces. One showing a ball-spring gizmo which moves according to acceleration sensor data received from the device. The disadvantage of such an approach is that the visualization overlays content on the smartphone and thus, may be annoying for the user. The second interface moved the whole text displayed on the smartphone according to incoming acceleration forces. Study results for both interfaces did not suggest a significant improvement on the symptoms of motion sickness. Nonetheless, their study setup of filling a bus with participants and having them wear view-limiting hoods was innovative. It allowed them to evaluate a reasonable sample size (N=26) at the same conditions.

Miksch *et al.* [23] took a different approach and provided a live video feed in their Motion Sickness Prevention System (MSPS). The video stream was visualized in form of a semi-transparent background for tablets behind a text. Most participants stated that they rated the implemented interface as very helpful and their results emerging from the conducted motion sickness survey [20] showed just as much. This system has the technical barrier that a front-facing camera would have to be mounted and the video data transmission delays need to be kept at a minimum.

In addition, there are several apps for mobile devices promising mitigating effects on motion sickness. However, most of them concentrate on instructing the driver on a driving style that induces less motion sickness. Two applications were found that took a related approach to Bubble Margin. The Anti Motion Sickness App³ simulates radial waves across the screen. The KineStop - Car sickness aid⁴ provides a semi-transparent artificial horizon overlay. For both apps no empirical evidence of actual mitigating effects is available. Various other interfaces trying

³ <https://play.google.com/store/apps/details?id=com.scy.chaeyoung.tbsm2> - Accessed 26.01.2019

⁴ <https://play.google.com/store/apps/details?id=com.urbandroid.kinestop> - Accessed 26.01.2019

to prevent motion sickness for travelers circulate on social media platforms. For example, car manufacturer Citroën has recently launched a product called SEETROËN⁵ in form of eyeglasses with a liquid-filled frame.

These approaches have shown that there is potential for mitigating motion sickness by providing visual cues. For our approach, we wanted to use a passenger's smartphone for visualizing such cues, since most people take their smartphones with them anyways and everywhere. In the next section, we describe design decisions and implementation information for the Bubble Margin approach.

3 Bubble Margin Prototype

For the Bubble Margin prototype we need to make sure to be able to visualize the motion cues without interfering with a primary task such as reading on the smartphone. Secondly, motion cues need to have access to linear acceleration data in real-time. To increase accessibility, we decided not to use additional hardware on top of built-in sensors in a modern smartphone.

Most modern Android phones provide linear acceleration data out of the box in form of a software-based motion sensor using the device's gyroscope. For older devices, as well as modern low-budget devices a low-pass filter can be implemented in order to filter gravitational force from the accelerometer's data and further obtain linear acceleration data. Prior to designing the interface we had to ensure the possibility of drawing overlays on the device's screen. Android provides the `SYSTEM_ALERT_WINDOW`⁶ permission that needs to be granted once by the user and further allows an application or background service to draw above all other applications.

This also allowed us to implement Bubble Margin as a semitransparent graphical overlay with no touch functionalities. Touch gestures are handled by the layer below the Bubble Margin visualization and thus scrolling gestures are not affected.

3.1 Interface Design

To discuss various design ideas for the interface we have conducted an internal workshop with three HCI researchers and two interaction designers. Inspired by designs, as described in the related work section, various visualizations were discussed.

A design presenting visual cues in a single spot on the screen as in the ball-spring gizmo by Hanau and Popescu [16] was decided to be not suitable for smaller displays such as smartphones' as compared to those of tablets or e-readers. The visual cue would take up too much screen space in order to be of reasonable size. Creating a fullscreen overlay design that simulates outgoing radial waves could cope with the above mentioned problem of size. However,

⁵ <https://www.youtube.com/watch?v=aih3LgMoyvY> - Accessed on 26.01.2019

⁶ See <https://developer.android.com/reference/android/Manifest.permission> for more information - Accessed on 26.01.2019

we did not want the visual cue to lower usability of the smartphone itself by displaying information all over the screen. A fullscreen visualization might also distract from a primary task such as reading on the smartphone. Another idea was to show a banner at one side of the screen. While this idea was considered little intrusive, the movement space for objects would be rich for one planar axis but small for its perpendicular axis. Compensating inferior movement with additional metaphors, such as colors, did not seem intuitive enough for user's peripheral vision to comprehend.

In general, we ruled out all design ideas that were deemed as too disturbing or as too small to provide the necessary space for moving visual feedback cues. It is known that peripheral vision is good at detecting motion compared to detecting form [1], hence the interface should provide a rich movement space for visual feedback. That is why the final decision was made for a design based on a semi-transparent border, drawn at the margins of the screen. In addition to being mostly scrollable, text documents and websites tend to have unused space at the margins of the display. This enabled us to implement a little disruptive interface with enough room for indicators to move notable distances.

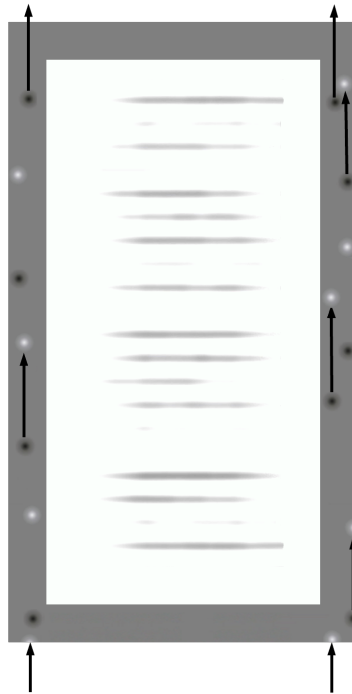


Fig. 1. Illustrated movement for Bubble Margin used in a car that is slowing down. Black bubbles show the position before braking. White bubbles show the position while slowing down. Arrows demonstrate bubble movement.

3.2 Visualization

Having decided to use the border of the smartphone as visualization area, we needed to decide how movement should be visualized. Again, we discussed several ideas. The two most promising were metaphors of raindrops and bubbles. Raindrops would have a fixed anchor point and display movement by morphing their form in the direction of the force. Since raindrops are familiar in the automotive context this metaphor was expected to be intuitive and natural. On the other hand, animating and visualizing raindrops in a natural way would require a lot of computational power. The effect of different amplitudes of forces might not be noticed by a user [1].

Thus, we decided to display movable objects indicating linear acceleration in form of circles, making them resemble floating bubbles (see Figure 1). Bubbles would have no fixed anchor-points but move freely inside the border. They are easier to implement than raindrops and open-up the possibility to be adaptable to user preferences. All bubbles move according to the direction and amplitude of a registered linear acceleration force. Additionally, a small random variance in movement amplitude was introduced in order to get a more natural feeling, such that they do not seem to move as one unit. Whenever a bubble moves outside the device's display or out of the border, it appears on the opposite site respectively.

Figure 1 illustrates the conceptual design of Bubble Margin. Bubbles move forward as the car is slowing down. Black bubbles indicate the position before braking, whereas white bubbles show a snapshot of its position while slowing down. Arrows demonstrate the way a bubble has moved. They are solely used for demonstration and are not a part of the actual interface. We have further implemented the option for users to freely change Bubble Margin's settings. Color, transparency and width of the border can be freely adjusted. Border size can be set to a specific dp (density-independent pixel)⁷ value. Bubbles can be adjusted in size and number. Additionally, transparency and color can be chosen. The user can set three colors independently forming a radial gradient.

3.3 Movement Design

As stated previously we used the smartphone's sensors to access linear acceleration data. To access gyroscope sensor data we used the android hardware package to implement a `Sensor_Event_Listener` registered with a `Sensor_Manager`. We then constantly saved the sensor values into an array⁷ updated every 20 milliseconds. These values were then used to inform the movement of the bubbles.

We factored raw data from the gyroscope to represent a smooth and natural bubble movement in the following way. First we simply added sensor data in x and y direction to the bubbles current position. This resulted in a smooth but

⁷ Density-independent pixels (dp) are an abstract unit based on the physical density of the screen. Units are relative to a 160 dpi (dots-per-inch) screen. One dp is one pixel on a 160 dpi screen. The ratio of dp-to-pixel will change with the screen density. $px = dp * (dpi/160)$ from <https://developer.android.com> - Accessed on 26.01.2019

to little magnitude movement. Thus, we amplified the movement by a factor 3.5, which we determined by trial-and-error until we were satisfied in the visual appearance. Additionally, we altered this factor randomly in a range from 50% to 150% in order to make the movements of the individual bubble more *natural* i.e. all bubbles moving in the same direction, but not all behaving exactly in the same magnitude.

The initial placement of bubbles was randomly inside the Bubble Margin's border by randomly generating x and y coordinates within the Bubble Margin border, which then were used as the center for bubbles.

In case the phone would not be equipped with a gyroscope, we used the acceleration sensor data from which we extracted earth gravitation by means of a low pass-filter and then removed this gravity by means of a high-pass filter. The basic idea behind that is to iteratively extract earth gravitation from the data by thresholding⁸. Feasibility testing with older devices where the low-pass filter was executed did not result in noticeable delays. For the study presented later we only used newer devices (all of the same kind to be able to compare results) and thus built-in gyroscope sensors were available.

In order to get the best results from sensor data the smartphone would need to be aligned in a horizontal position. Since sitting people hold their smartphone in an angle between zero and 20-degrees [21], acceleration data was interpolated in a vertical direction to cope with this. Additionally, it was made possible to set the current slope for continuous uphill or downhill rides, which allows for more accurate bubble movement.

4 Study Setup

In order to test the effect of Bubble Margin on mitigating motion sickness, a small-scale (N=10), within-subjects study was conducted in a real-driving scenario. The experimental setup aimed to recreate the common situation of passengers reading a text on their smartphone while driving on curvy countryside roads.

A test condition (TC) and a control condition (CC) were introduced, in which participants had to read a text with (TC) or without (CC) Bubble Margin while sitting in a driving vehicle. The vehicle was driven by a researcher. All participants needed to take part in both conditions. To rule out cumulative effects of motion sickness a minimum pause of two days was required between the conditions. Condition order was alternated to reduce the risk of one-sided habituation-affected results.

The control condition and the test condition both consisted of a 20-minute drive on a preselected road, known for little traffic and for allowing speeds up to 100 km/h. The route included serpentine and curvy roads. Distance was 15.3 km with an altitude difference of 211 meters. The driven course on the pre-selected road is shown in Figure 2.

⁸ https://developer.android.com/guide/topics/sensors/sensors_motion - Accessed on 2.06.2019

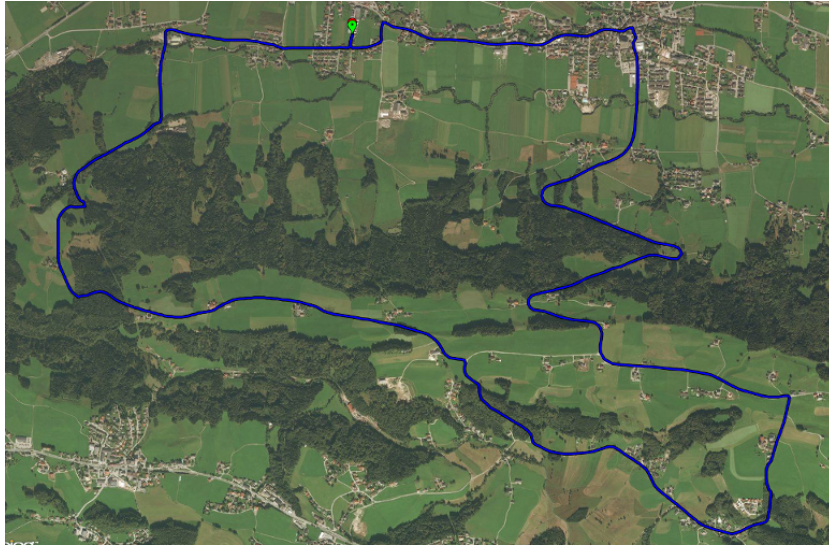


Fig. 2. Preselected route used for studying the mitigating effect of Bubble Margin on motion sickness.

In order to reduce study effort, we allowed up to three people participating in one ride. Thus, we needed to have three similar smartphones on which the Bubble Margin app was installed. All Android smartphones used for drives were *Sony Xperia Compact* models, providing a 4.6 inches display and a resolution of 720 x 1280 pixels at a 16:9 aspect ratio. The device has a built-in gyroscope sensor. In order to have comparable situations, screen brightness was set to the highest available level and not adjusting automatically.

Two different texts describing countries were prepared for participants to read, differing for both conditions. The font used for the texts was *Roboto* measuring a font size of 24pt visualized as pdfs in *WPS Office*⁹. The text was shown inside the Bubble Margin borders. We chose the reading task specifically as it is often attributed to induce motion sickness. It is a typical task on mobile devices and we could validate whether subjects were actually looking at the smartphone by asking comprehension questions. With respect to validity regarding the reading task, we counterbalanced the visualized text and used differently ordered conditions.

In the final version of Bubble Margin users will have the possibility to choose how many bubbles they want to have visualized, in customised color and size, etc. For the study we wanted to have comparable conditions. Thus, we tried out various settings on our own. We experimented with different margin sizes and number and sizes of bubbles. The margin should be small enough so that the

⁹ *WPS Office - Word, Docs, PDF, Note, Slide & Sheet* by Kingsoft Office Software Corporation Limited. *Effizienz*

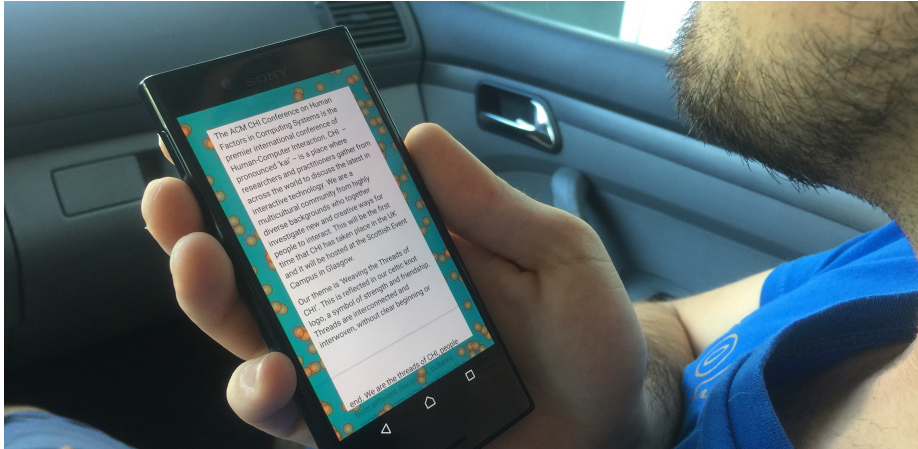


Fig. 3. The Bubble Margin is a smartphone application to mitigate motion sickness while reading in a moving vehicle visualizing motion cues in form of bubbles at the margins of a smartphone.

text in the center is still visible, but broad enough to visualize enough bubbles. Our aim was to get enough bubbles that are equally distributed within the BubbleMargin border (all areas i.e. left, right, bottom, top). We then presented different variations to colleagues. They were given the chance to change settings keeping in mind that the bubbles shall be noticeable when reading a text but not too distracting.

This resulted in 200 bubbles, measuring a radius of 10 dp and filled by a white to transparent radial gradient color. They were randomly placed inside a 16 dp wide, semi-transparent gray border. For the study these values were kept the same for all participants. We do not claim that this is the most usable setting, but they seemed to be a fair balance between readability of the text in the center of the screen and enough visual information for the Bubble Margin approach to be perceivable by users. Figure 3 visualises the setup for subjects. For demonstration reasons the border width as well as text content and colours were changed.

As individual drives included up to three participants, seating positions were noted and it was assured that they did not differ for both conditions. For each ride, the driver was instructed to record the outside temperature, weather conditions, as well as traffic conditions. Temperature inside the car was to be constantly kept at 20.0° Celsius.

4.1 Demographics

Six females and four males of age between 21 and 60 volunteered to take part in the study. They were recruited among colleagues not familiar with the project.

All of them stated to have experienced more or less severe effects of motion sickness as passengers before.

Prior to the first ride, participants were asked to fill in a short version of the Motion Sickness Susceptibility Questionnaire Short-form (MSSQ-Short) [11, 13] to get a measurement of their general susceptibility to motion sickness. The MSSQ-Short was scored as proposed and percentiles were approximated using the polynomial described by Golding [13]. The resulting MSSQ percentiles ranged from 28.6 to 100 with a median of 77.85. A high MSSQ percentile suggests high susceptibility to motion sickness.

4.2 Subjective Well-Being

Prior to each of the two rides participants were asked to report their physical state. This included questions regarding alcohol or drug consumption within the last 24 hours. We additionally assessed how long ago they had eaten food or drunken fluids. In order to establish a general baseline, all participants were asked to score their overall well-being from 1 to 9 before both conditions.

4.3 Study Procedure

The study procedure is shown in Figure ???. Before the first ride participants were informed about the aims and risks of the study. We especially, informed participants about the risk of becoming motion sick during a ride. They were informed that they could stop the ride at any time, if they felt too uneasy to continue. After signing an informed consent participants filled in demographic data and the MSSQ.

Then for each of the two conditions participants had to answer the above mentioned subjective well-being questions. As proposed by Karjanto *et al.* [19], the change in participants' motion sickness level was determined by applying the Motion Sickness Assessment Questionnaire (MSAQ) [10] before and after each drive. The MSAQ is used to assess four dimensions of motion sickness, defined as *gastrointestinal*, *central*, *peripheral*, and *sopite-related*. An overall score can be derived by ignoring dimensions and calculating the percentage of total points scored. Bubble Margin's effect on easing motion sickness was determined by taking the difference in scores for the control condition and the test condition.

During the ride participants were asked to take note on a protocol whenever they had to move their vision away from the text. The protocol consisted of three images on a sheet of paper: look away from the phone, look outside the window, stop. Participants should indicate with a dash next to the image whenever they looked away from the screen or outside the window. The effort for participants was very low. We wanted to record this behavior in order to be informed about coping strategies of participants with respect to motion sickness. If a participant would require the vehicle to stop, we would have noted time and reason.

After they had finished riding and completed the second MSAQ, a post-study questionnaire was filled-in. Questions with respect to readability and understandability needed to be answered on a Likert-like scale from one to nine. To validate

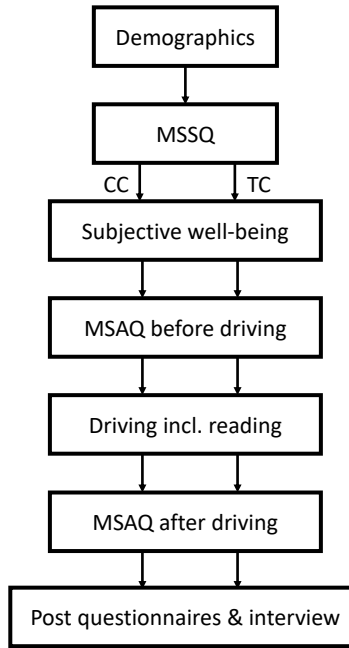


Fig. 4. Flow diagram showing the study procedure.

the participants' attention to the text, they had to answer ten dichotomous questions regarding its content.

After the control condition, we further asked participants to state on a scale from 0 (never) to 3 (often) if they had intentionally or unintentionally looked at the moving bubbles. A Likert-like scale (1-9) was used to assess if participants felt disturbed by Bubble Margin and if they would consider using the application in the future. Participants were also asked to change Bubble Margin's settings according to their own preferences in order to give feedback on their preferences. That was done stationary and not in the moving vehicle. These settings were not used as an input to the study but as a feedback afterwards.

5 Results

A Wilcoxon signed rank test (WSRT) was applied to the overall well-being baseline score. The analysis showed that overall well-being was not significantly different at the beginning of both conditions ($z = -0.707$, n.s.).

WSRT results on MSAQ score differences showed that the total motion sickness level was significantly lower in the test condition, compared to the control condition ($z = -2.346$, $p = 0.0095$, one-tailed). Changes for specific motion sickness dimensions were significant for gastrointestinal, central, and sopite-related dimension, as well as for the total score (see Table 1 for detailed results). Only

the motion sickness change for the peripheral dimension was found to be not significant. This result leads to the assumption that Bubble Margin does have a potential positive effect on motion sickness symptoms.

Table 1. MSAQ results from Wilcoxon signed rank test as well as means and medians for the control condition (CC) and the test condition (TC). Scores for statistical analysis were derived by subtracting the pre-drive MSAQ scores from the post-drive MSAQ scores.

| | mean CC | mean TC | median CC | median TC | z-value | p-value (two-tailed) | p-value (one-tailed) |
|------------|------------|------------|--------------|--------------|---------------------|-------------------------|-------------------------|
| total | 12.082 | 2.638 | 8.335 | 0.040 | -2.346 ^a | 0.019 | 0.0095 [*] |
| gastro | 16.112 | 4.999 | 12.500 | 0.000 | -2.549 ^a | 0.011 | 0.0055 [*] |
| central | 15.333 | 3.779 | 7.775 | 0.000 | -1.859 ^a | 0.063 | 0.0315 [*] |
| sopite | 11.945 | 0.833 | 9.725 | 0.000 | -2.176 ^a | 0.030 | 0.015 [*] |
| peripheral | 1.481 | 0.740 | 0.000 | 1.850 | -0.142 ^b | 0.887 | 0.5565 |

^{*} The result is significant for $p < .05$, one-tailed.

^a Based on positive ranks.

^b Based on negative ranks.

We further conducted a Spearman-Rho rank correlation in order to check upon a correlation of susceptibility (MSSQ-score) and occurred motion sickness (MSAQ-score). We found a highly significant positive correlation (Spearman-Rho=0.796, $p < .01$) for the control condition. The correlation was a bit lower for the condition with the Bubble Margin (Spearman-Rho=0.723, $p < .05$). In general that means that participants, who were more susceptible to motion sickness, were also more likely to get motion sick during the study.

Outside temperatures varied from 15.0° to 27.0° Celsius with medians of 19° Celsius for the control condition and 25° Celsius for the test condition. The weather ranged from sunny to cloudy and traffic was trivially low at most times. For the control condition, one test person (TP8) has stated to have drunk alcohol within 24 hours prior to the study. The test condition consisted of three participants (TP3, TP7, TP8) drinking alcohol within 24 hours prior to the study. After asking for details they all confirmed to have drunk a trivial amount the night before. TP7 and TP10 have taken medication 24h prior to driving in both conditions, while TP8 only stated likewise for the test condition. General well-being was rated between 6 and 9 for both conditions for all participants but one, meaning that they felt well before the rides. TP7 rated general well-being only with 4 for the test condition, mentioning that he felt a little bit dizzy.

Regarding looking out of the window to mitigate motion sickness the following answers were given. During control condition, two participants (TP 2,3) looked away from the text and out of the window once and TP1 did so twice. For the test condition TP1 looked out twice and TP7 once. All others stated to have constantly had their vision fixed on the phone. Three people (TP 2,5,6) have stated that they had intentionally looked at the moving bubbles at times.

More than half of the participants (TP 1,2,3,7,8,10) unintentionally moved their vision to the bubbles rarely or sometimes. Percentages scored in the text understanding test ranged from 60% to 100% with medians of 90% (CC) and 95% (TC).

For both conditions median values for font readability was 8.5 and for text understandability 9, rated on the Likert-like questionnaires scaled from 1 (not at all) to 9 (very much). The median for Bubble Margin being irritating was 1.5. For participants considering to use the application in private the median value was 9. With respect to individual configuration most participants were satisfied with the pre-settings. TP1 would have liked less bubbles on display (100 instead of 200), as well as slower movement. TP5 wished for the border to be wider (30 dp instead of 16 dp). Color configurations for bubbles and the border were individually different and based on personal preference.

6 Discussion

The study has shown that the overall assessment of the Bubble Margin approach was positive both with respect to its mitigating effect on motion sickness, as well as to usability related aspects.

We could show a significant improvement regarding motion sickness symptoms for the test condition. The only dimension that did not create a significant effect was the peripheral score. This score included questions with respect to subjective temperature feeling. Although, we tried to have a stable temperature inside the vehicle the outside temperature was not consistent for all drives. This could be a possible reason for these results.

In the study participant could sit on different seats in the front or at the back. We only made sure, that they sat at the same position for both rides (CC and TC). We did not find any effects on motion sickness based on the sitting position of participants. Although none of the participant felt really sick during rides, some indicated that they had to look outside the window because they felt uneasy. This was not only the case during the control condition, but also while using Bubble Margin. This leads us to the assumption, that there are limits to the mitigating effects of Bubble Margin.

We could also show, that applications like Bubble Margin have a stronger effect on people who are more susceptible to motion sickness. This result does not come as a surprise, since Bubble Margin seems to be unnecessary for people not being susceptible to motion sickness. One participant (TP5) complained about migraine prior to the test conditions drive. This was not the case for the control condition. It is worth mentioning that Bubble Margin had an opposite effect on her, amplifying motion sickness symptoms. Her migraine might have had an effect on this outcome, which has already been shown in [18]. This, also shows that there is no universal applicable visualization of motion that mitigates motion sickness, supporting [22].

With respect to the Bubble Margin design the visualization was not perceived as being peripheral at all times since participants either intentionally or

unintentionally looked at the bubbles from time to time. Since the application was new to them this could be due to novelty effects. However, participants stated that this had a positive effect on subjective well-being. One could argue that looking at the Bubble Margin may be positive since mental distraction was shown to have a positive effect on motion sickness [5].

The overall functionality and stability of the Bubble Margin application proved to be faultless and stable. None of the participants reported any problems with regards to dysfunctioning visualizations or inconsistencies. These facts allow for Bubble Margin’s source code to be used as a foundation for future projects to build on.

From a methodological point of view, the reading task was conducted well by all participants, which implies that the Bubble Margin visualization allows for doing such tasks while being visible at the smartphone margin, even with relatively small displays as we used in the study. With the current increase of size of new smartphones and phablets Bubble Margins might be even more effective.

6.1 Limitations

One limitation of the study is the low number of participants. The decision was ultimately one between breadth and depth. Since motion sickness is not yet fully understood with influencing factors sometimes differing from individual to individual, we opted for an in-depth assessment on a smaller sample. We chose a within-subject study design in order to find individual differences, which we did in the end. People are different in their susceptibility to motion sickness and this is also dependent within a subject (e.g., time of the day, general well-being, medication). While we tried to limit confounding factors as much as possible e.g., chose the same route for both rides, chose the same time of the day (to have similar light and traffic conditions), asked for influencing factors such as alcohol consumption, or eating behavior.

Another limitation is the recruiting among colleagues not familiar with the project. This had mainly procedural reasons. We wanted to conduct a within subject-study having participants to drive twice in a reasonable timely distance to each ride not to have sequence effects, at the same time wanting to have both rides as soon as possible after each other. Additionally, we wanted contextual factors to be as stable as possible (weather, outside temperature) since they also might have an influence on motion sickness. We argue that, the subjective feedback about the Bubble Margin approach in general might be biased, but whether it helps to fight motion sickness is probably not subject to such a bias.

The decision to inform participants in advance about potential risks could have priming effects on motion sickness. Due to ethical reasons we decided to inform participants about potential well-being related risks in advance. We cannot entirely exclude biases with respect to that.

Our study indicates that the Bubble Margin has a mitigating effect on an individual, subjective level. Participants were eager to use Bubble Margin for their private purposes in the future. That showed us the potentials of it. Results show the potentials of Bubble Margin, but cannot be generalized and need

further verification. Data on acceleration forces could provide additional insight into the severity of induced motion sickness, as shown by Karjanto *et al.* [19].

7 Conclusions

In this paper, we have presented a novel approach to mitigate motion sickness while driving. Bubble Margin provides visual cues, shown at the border of a smartphone based on acceleration forces in real-time. Bubble Margin is designed to run on a mobile device regardless of the content displayed in the center of the screen. Its value lies in the fact that it does not need any additional hardware and might be used as an overlay for any possible application. As such it is crucial that it is not perceived as being distractive from a primary task, such as reading, while still having a mitigating effect on motion sickness. An initial study showed, that Bubble Margin has mitigating effects on motion sickness during a reading task. With the raise of autonomous vehicles and the omnipresence of smartphones we believe, that approaches such as Bubble Margin have the potential to reach a large number of people.

Future work, needs to investigate what effect different designs have on mitigating motion sickness. For example, what is the minimum number of bubbles to evoke these effects? What effects have margin width and color?

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