The effect of peripheral cues on motion sickness mitigation when using a VR HMD in a car

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Virtual Reality (VR) is a promising candidate for an in-vehicle personal viewing system. However, motion sickness caused by VR in vehicles is a major obstacle to its use. In this study, we propose mitigating motion sickness by presenting peripheral cues that are integral to a VR scene. The cues react to the vehicle's rotation with a three-dimensional opposing rotation. An on-road experiment was conducted to evaluate whether the peripheral cues mitigate motion sickness. Outcomes were assessed by both subjective motion sickness ratings and physiological responses. There are two conditions: watching a video with the cues and without the cues. Results indicate that motion sickness gradually increased with exposure time, and the mean levels of motion sickness were lower when the cues were presented. We discuss how these results are related to the cue design and suggest directions for future work.

INTRODUCTION

Advances in automatic driving will enable drivers to reduce the cost of driving, allowing them to perform productive activities and enjoy various entertainments in vehicles (McGill et al., 2019). Indeed, these technologies promote the use of personal viewing systems in vehicles, such as watching video clips with a car monitor, smartphone, or laptop (Hecht et al., 2020). Virtual Reality (VR) is a promising candidate in this domain as there is limited physical space for a personal viewing system in a vehicle. VR has the advantage of presenting a large field of view in a compact portable Head-Mounted Display (HMD). Thus, many studies of VR applications in vehicles have been explored, such as a flying game (Hock et al., 2017) and or more passive activities such as viewing a country house or an underwater river environment (Paredes et al., 2018).

However, despite these advantages, users of VR in vehicles frequently struggle with motion sickness and experience symptoms of nausea, vomiting, headache, salivation, and drowsiness (Graybiel et al., 1968). The Sensory Conflict Theory (SCT) suggests that motion sickness results from a discrepancy between sensory cues or expectations and motion sensations (Reason, 1978). In VR environments, a mismatch of visual sensory cues with the actual body movements potentially increases the sickness (Hettinger et al., 1990). Previous studies observed that the severity of sickness symptoms produced by VR grows with the exposure time (Dużmańska et al., 2018; Kim and Shin, 2021; Chen and Weng, 2021). To mitigate the motion sickness severity, reducing the immersive sense of VR has been suggested via techniques such as narrowing the HMD Field of View (FOV) (Choroś and Nippe, 2019) and blurring the FOV (Nie et al., 2019). A low frame rate, which decreased the detail of the VR scene, also reduced motion sickness levels (Choroś and Nippe, 2019).

These problems are exacerbated when viewing the content in a vehicle, as the motions of the vehicle are typically unrelated to those depicted in viewed scenes. To address this problem, several studies have sought to mitigate motion sickness in vehicles by reducing the sensory conflict between the content being viewed by the passenger and the vehicle's motion. One approach has been to enhance awareness of car movements with notifying systems, such as providing visual information about upcoming car movements on peripheral LED (light emitting diode) light displays (Karjanto et al., 2018) or visualizing information about acceleration forces at the margins of a smartphone screen (Meschtscherjakov et al., 2019). Motion sickness from VR use in a vehicle is more complicated as it can be due to both the VR environment and the vehicle's motion. McGill et al. (2017) showed that peripheral visual feedback of a moving landscape reflecting a vehicle's rotation and acceleration could slow the onset of motion sickness, although it could not reduce its final level. While this work is promising, we note they used external rotation and On-board Diagnosis (OBD) sensors to track car movements and suggest that latency attributed to these devices may have contributed to elevated sickness levels due to an inability to capture or convey relatively rapid vehicle oscillations.

This ongoing study seeks to reduce the motion sickness from in-vehicle VR by delivering rotational information about the vehicle via background cues. One of the contributions of this ongoing work is that the background cues are designed to rotate around the user's position as opposed to the car's rotation. Displaying rotating cues that move in a three-dimensional direction may better integrate with a display of VR contents. In addition, we ensure that cues are well-synchronized with the car's real-time rotation by using data from the embedded Inertial Measurement Unit (IMU) in the HMD. Second, this study evaluates the effect of peripheral background cues in a moving car by both rating subjective motion sickness (Dużmańska et al., 2018) and measuring objective physiological responses: heart rate, respiration rate, and skin conductance level (Wan et al., 2003; Javaid et al., 2019) to report how these vary with reported levels of motion sickness.

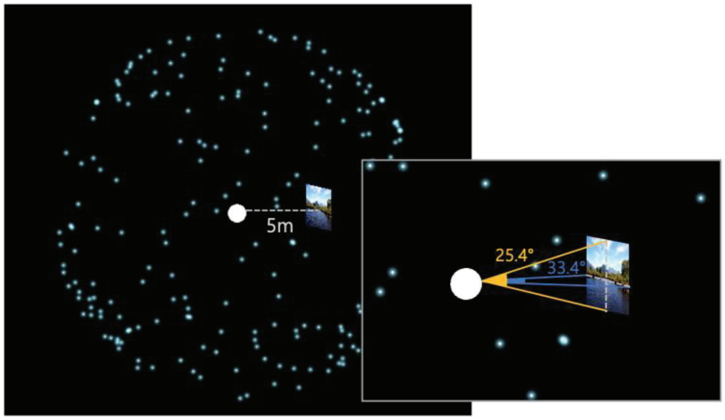

Figure 1. Virtual environment and screen size. The white circle shows the participants' position.

Figure 3. A participant wearing an HMD and sensors for measuring physiological responses in the car.

METHODS

Participants

Four young male participants without current or previous neurological problems participated in this preliminary experiment (Table 1). All participants provided consent to a protocol approved by the institutional review board before participating in the experiment. Participants rated how often they felt sick or nauseated in the past using the short-form Motion Sickness Susceptibility Questionnaire (MSSQ) (Golding 1998). The MSSQ score converted to a percentile score. Participants 1, 2, 3, and 4 had 12th, 10th, 47th, and 0 percentile scores, which means they were more susceptible to motion sickness than others who scored lower.

Table 1. Participant information. Values are means (SD).

Gender	MSSQ score, percentile	Age, years	Height, cm	Weight, kg
M (n=4)	17.5 (17.9)	24.5 (1.7)	175.2 (12.2)	72.5 (12.2)

System & Study design

A commercial HMD, Meta Quest2, was used with a resolution of 1832x1920 pixels per eye and a frame rate of 60Hz. This system adopted 3-Degree of Freedom (DoF) to keep the participant's position at the center of the VR scene when the vehicle moves and rotates. In all conditions, participants were required to watch a video clip that presented the comfortable and peaceful natural landscape (Figure 2). The screen for playing the video clip was placed 5m from the participant's location. It had an aspect ratio of 4:3 with the Field of View (FOV) of 33.4° horizontally and 25.4° vertically (Figure 1). Using the embedded IMU sensor in HMD, the screen faced the participant and rotated only on the yaw-axis with the vehicle's rotation. A low pass filter (One Euro Filter) was used to control the subtle shaking of the screen caused by the vehicle.

The study had two conditions for the background setup; watching the video clip 1) 'Without background cues (No cues)' and 2) 'With background cues (Cues).' In the 'Cues' condition, 200 blue light cues were randomly placed on a sphere with a radius of 10m centered on the participant (Figure 1). The background cues had a radius of 0.1m (FOV: 1.15°) and took

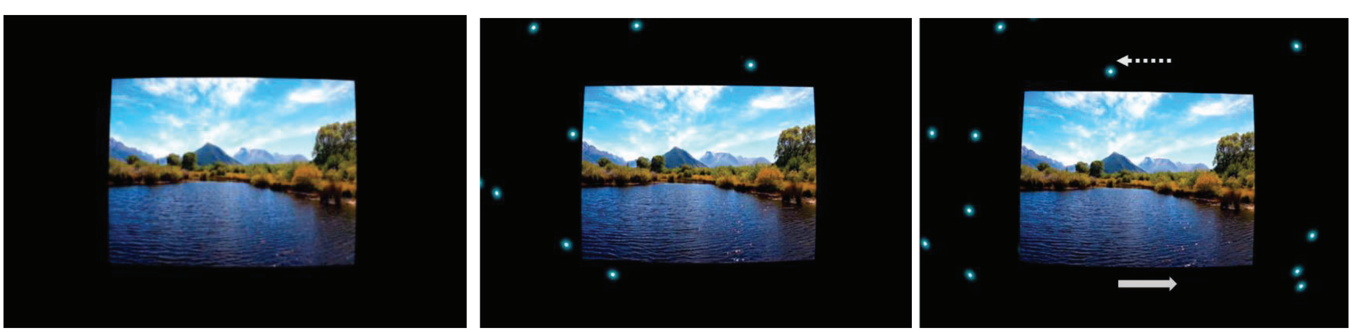

Figure 2. (Left) Video screen without cues. (Center) Video screen with cues. (Right) When the car rotates 10 degrees to the right (thick arrow), participants in a virtual environment see the cues as moving 10 degrees to the left (dotted arrow). Arrows were not shown in the experiment.

Figure 4. Driving course (green line, total distance: 3.1km). Seven points show car location at each minute.

the form of bright blue light spheres, as this is effectively detected in peripheral vision (Ancman, 1991). Since the cues remain in the same position where they are initially placed in the VR scene, the rotation of the vehicle makes the cues around the participant appear to rotate. It enables participants to be aware of the vehicle's rotation indirectly while watching the video clip. In the 'No cues' condition, on the other hand, only the video clip was presented with an empty black background.

Measurements

In this study, there were two types of measurements to evaluate motion sickness: a subjective motion sickness rating and objective physiological responses (electrocardiography, skin conductance level, and respiration rate). Subjective motion sickness was rated with a 7-item scale: 1=no symptoms; 2=any slight symptoms; 3=mild symptoms such as stomach awareness but no nausea; 4=mild nausea; 5=mild to moderate nausea; 6=moderate nausea; 7= moderate to severe nausea and want to stop (Wan et al., 2003).

For the electrocardiography, a negative electrode was placed below the ribs on the right, a positive electrode was placed at the same level on the left, and the ground electrode was attached upper sternum area. The raw electrocardiography signals were band-pass filtered between 2Hz and 40Hz, and heart rate was calculated. Two skin conductance sensors were attached to the forehead. The raw data were low pass filtered with a 0.4Hz cutoff frequency. The respiration rate was measured using a strain gauge sensor around the thorax. The gauge sensor data was filtered with a low pass filter with a 0.5Hz cutoff frequency and the number of peaks divided by time duration to calculate the respiration data.

All physiological responses were recorded at 2048Hz using a physiological data acquisition system (Flexcomp, Thought Technology Ltd., Quebec, Canada) and were normalized to their mean values at rest time collected before starting each condition.

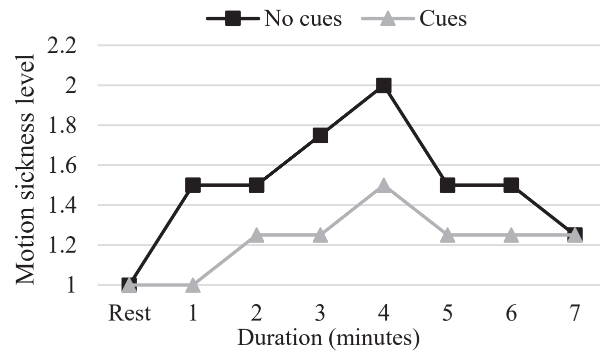

Figure 5. Mean motion sickness level during the course.

Procedure

Participants conducted one condition per day to ensure no carryover of motion sickness between conditions. The order of conditions was balanced and randomized. The experimenter first attached the sensors for measuring the motion sickness to the pre-defined body locations of participants. Then, a participant was seated on the right back seat of the car, and the experimenter sat on the left-back seat to control the measuring devices and monitor the participant (Figure 3). At the starting point of the driving course, the participant took a 10-minute rest. During this period, each baseline of the physiological responses was collected. After the rest time, participants wore the HMD. As the vehicle started, they started watching the video clip in the VR scene, and the experimenter started recording the physiological responses.
A driver drove the vehicle (KIA, Carnival) along the driving course. The driving course was a low-traffic road, and it included a traffic circle and turn sections (Figure 4). The course took about 8 minutes. The car speed was maintained at 30km/h. In both conditions, the subjective motion sickness level was rated verbally in the rest period and every 1 minute during the study.

RESULTS

The motion sickness level gradually increased along the exposure time, and it was the highest around 4 minutes (Figure 5). In terms of both subjective rating and physiological responses, the mean motion sickness levels were generally lower in the 'Cues' condition (Table 2).

Table 2. Mean (SD) of physiological responses for conditions.

Measures	No cues	Cues
Mean motion sickness level	1.5 (0.5)	1.2 (0.2)
Heart rate (%)	106.3 (6.8)	103.7 (7.2)
Respiration rate (%)	122.2 (20.3)	121.3 (18.3)
Skin conductance level (%)	174.7 (54.1)	108.1 (10.6)

DISCUSSION

In the current study, changes in motion sickness level and physiological responses have been investigated to examine whether peripheral background cues would mitigate the motion sickness from VR in a moving car. Due to the small sample size of this ongoing study, the partial and preliminary results only show trends of motion sickness symptoms.

Overall, the motion sickness symptoms for the 'Cues' condition tended to be near no and slight symptoms in both subjective rating (1 to 1.5) and objective measures (108.1% (SD=10.6) of skin conductance level), while the 'No cues' condition was near slight and mild symptoms (1 to 2 of subjective rating, 174.7% (SD=54.1) of skin conductance level). It indicates that the sensory conflict may have decreased in the 'Cues' condition. It reflects the high situation awareness provided by the peripheral visual cues, similar to that observed in a prior study (Karjanto et al., 2018). In addition, since the peripheral background cues rotate in three dimensions and the opposite direction to the car's rotation, our technique was able to provide similar situation awareness to that of participants looking through the car windows. Future work should further investigate the design of stimuli consistent with physical laws when delivering the rotational information.

In terms of the exposure time and road situation, the motion sickness levels were highest in both conditions after about 4 minutes and during the period in which the car engaged in a 360-degree turn (around a rotary road feature). After completing this turn, motion sickness levels were somewhat relieved. This suggests that motion sickness increases during the sharp and sustained vehicle rotation despite the cues we present. It would be important to extend our current technique with a specialized cue design for sharp and prolonged turns.

In the previous studies, an increase in motion sickness has a positive relationship with the increased heart rate, respiration rate, and skin conductance level (Wan et al., 2003; Dahlman et al., 2009). In the current study, only skin conductance level was positively related to motion sickness, while other physiological responses showed consistent levels. However, since we report on a small sample size with large deviations, our data here are currently preliminary. A larger sample will increase confidence in the measures of physiological responses we report.

In the case of individuals, participant 4 had never experienced motion sickness (MSSQ score = 0 percentile) and reported that he didn't feel any motion sickness during the experiment in both conditions. On the other hand, participant 3, who is relatively susceptible to motion sickness (MSSQ score = 47 percentile), reported that his motion sickness symptom was relieved in the 'Cues' condition. It implies that the effect of the background cues varies depending on individual motion sickness susceptibility.

The current ongoing study explored motion sickness from VR in a vehicle with peripheral background cues that exhibit rotations that oppose the car's rotation in three dimensions. Despite the results of this study showing that the peripheral background cues tend to mitigate motion sickness, future work is required to increase confidence in the results with a larger sample and formal statistical analysis. Additionally, it would be worth designing different types of cues based on the vehicle rotations, with sharp and sustained rotations likely requiring a specific customized design. We believe that our efforts to mitigate VR motion sickness in vehicles will be important in promoting the use of VR as an in-vehicle personal viewing system.

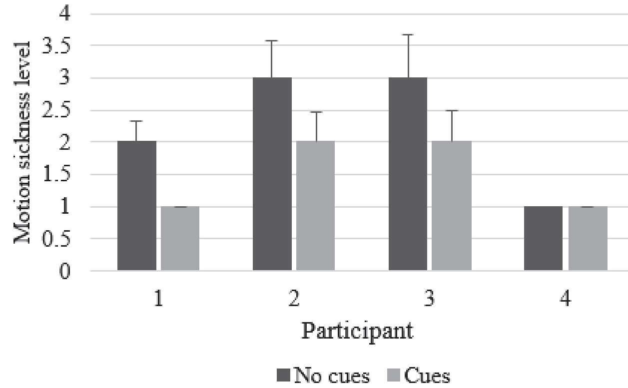

Figure 6. Mean of subjective motion sickness ratings of each participant for conditions.

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