Display Rotation for Reducing Motion Sickness Caused by Using VR in Vehicles

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ABSTRACT

Virtual Reality systems have the potential to change the way we interact with digital content in vehicles. However, wearing a VR headset in a vehicle may increase the chances of experiencing motion sickness. There is an open question as to how to convey visual motion alongside VR content to reduce motion sickness. This research explores possible countermeasures to alleviate motion sickness by delivering visual cues of physical motion through the position of virtual displays, implicitly conveying the motion without the need for additional distracting visual cues, which could alleviate motion sickness. The results showed that such visual cues significantly reduced symptoms associated with motion sickness. We expected our findings to lead to concrete suggestions to optimize VR user experiences and user comfort in vehicles.

CCS CONCEPTS

• **Human-centered computing**; • **Human-computer interaction (HCI)**; • **Interaction paradigms**; • **Virtual reality**;

KEYWORDS

VR use in vehicles, Motion sickness, Rotation chair

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1 BACKGROUND AND MOTIVATION

With the arrival of autonomous driving in vehicles, our travel experiences will be longer [1]. Longer journeys mean that passengers will require more entertainment and work options. Virtual Reality systems are valuable for solving these problems by providing engaging, immersive human-computer interactions using an interactive VR system. However, there are questions about possible problems for passengers using virtual reality headsets in vehicles, and motion sickness is one of them [2].

A possible explanation is that motion sickness is caused by the mismatch of the visual and vestibular systems [3]. Generally, the vestibular system of the human inner ear is composed of otolith organs and semicircular canals used to sense gravity and horizontal/vertical rotation [4].

While traveling inside vehicles, passengers experience different motions throughout the journey, and potentially over a long exposure time, so motion sickness can be a serious problem. When passengers use VR headsets, the movement on the display may be inconsistent with the movement of the vehicle. This will lead to serious motion sickness symptoms because of the conflict between visual and vestibular signals [5].

Many studies have demonstrated that it is possible to reduce motion sickness through different methods while using a head-mounted display. As McGill et al. demonstrated, motion sickness is minimized by matching the movement conveyed by a VR headset with the movement perceived by the actual body [6]. Also, according to Cho et al., the motion sickness level was reduced by constantly changing a virtual road in the VR display to accord with the vehicle's movement [7]. This is because the changing virtual road can match the vestibular sense.

These studies provide insights into the design of VR interfaces. In vehicles, passengers may use some software with VR, such as VR Desktop or Immersed. When using this software, a rectangular interface will appear in front of users. When the vehicle is in motion, the static rectangular interface and dynamic vehicle movement will lead to a mismatch between vision and vestibular organ information. This mismatch can lead to the development of motion sickness. Therefore, some effective visual cues that correspond to the vehicle's actual movement are needed to alleviate the symptoms of motion sickness.

In this study, we designed a proxy for a planar 2D virtual display as a visual cue. We attempted to explore whether the rotation of the rectangular interface in VR was an effective visual cue and whether this design could slow down the accumulation of motion sickness.

In this paper, we first describe the design of the rotation visual cues. Then, we present the design of the experiment and the results

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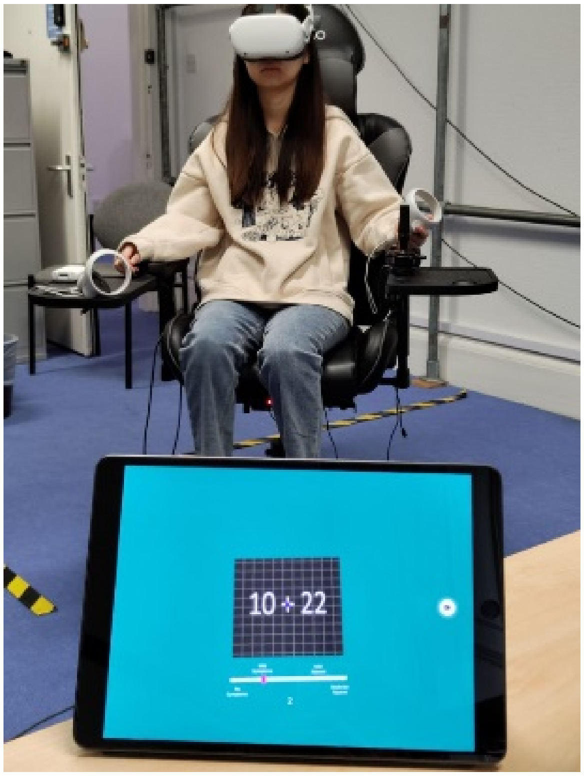

Figure 1: A participant experiencing rotational motions on the chair. On the tablet is a screen mirrored view of the participants experience, where they could see a math question on the virtual display, and a slider for indicating their real-time motion sickness

of the experiment. Finally, we summarize our findings and indicate some possible future research directions.

2 EXPERIMENT DESIGN

2.1 Experimental Equipment

We used a chair with a rotation motor that can do 1dof rotation around yaw/y-axis as a way to induce motion sickness platform. The chair could randomly rotate 45 degrees to the left or right to simulate vehicle steering in the city. The interval between each rotation was about 5 seconds. We used Meta Quest 2 as the VR platform. During the experiment, participants put on the VR headset and sat on the rotating chair for the experiment. This experiment has passed the ethics review. Figure 1 shows a participant taking the experiment.

2.2 Measurement Method

Two methods for measuring motion sickness were used in the experiment. The first method was the SSQ (Simulation Sickness Questionnaire) developed by Kennedy et al.[8]. It is a method widely used in motion sickness research. After completing a condition of experiments, the participants filled out the SSQ describing their experiences and the level of motion sickness they felt during the experiment.

The second method was a real-time motion sickness slider. The slider values ranged from 0 to 7 and appeared in the participant's field of view at the bottom of the VR screen during the experiment. The numbers represented were shown in Table 1.

2.3 Productivity Measurement

We employed two-digit addition and subtraction as an assessment of the participant's productivity. Participants were asked to answer math questions as quickly as possible. These questions were updated every seven seconds and no answer would be counted as a wrong answer.

We also used a secondary attention task (requiring the participant to press the trigger on the VR handle when a red dot turned blue) to ensure that the participant's visual attention stayed on the task plane.

2.4 Visual Cues

In the VR display, the math problems, motion sickness sliders, and secondary attention tasks are all in the same plane. The rotation of the plane around the participant is used as the visual cue. When no visual cues are applied, the difference between the rotation angle of the plane and the rotation angle of the chair is 0. When the participants sit on the rotating chair and are rotated, the task plane remains in front of the chair.

When applying visual cues, the difference between the plane and chair rotation angles equals the chair rotation angle multiplied by 0.3. When participants sit on the rotating chair and rotate with the chair, the task plane moves in the opposite direction to the chair movement in the participant's field of vision. Figure 2 shows how the task plane moves when the chair is rotated.

2.5 Experiment Procedure

At the beginning of the experiment, participants were reconfirmed whether they fully met the experimental requirements. Then participants put on the VR headset and sat on the rotating chair to start the experiment. First, participants used a beginner tutorial that was used to help those participants who were unfamiliar with VR.

If participants completed all the required tasks well, they would enter the second condition, participating in a motion sickness benchmark test that lasted for five mins. In this condition, the rotation of the chair would lead to an increasing experience of motion sickness while there were no visual cues. We set this condition as control condition. After that, participants rested for about ten minutes to avoid the cumulative effects of motion sickness. The next condition would start only when they believed they had no related symptoms. If participants were unable to return to baseline sickness within the experimental period, their data were excluded. If they were well-rested, the next test would begin. In this condition, the chair rotated while visual cues were supplied. We set this condition as experimental condition. In addition, for all participants, the order of the experiment conditions was counter-balanced by carrying out according to a Latin matrix [9] to minimize the accumulation of motion sickness.

Table 1: Motion sickness slider measurement and description

Value	Description
0	No symptoms
1	Any symptoms
2	Mild symptoms
3	Medium symptoms
4	Slight nausea
5	Mild nausea
6	Mild to moderate nausea
7	Moderate nausea (experiment stop line)

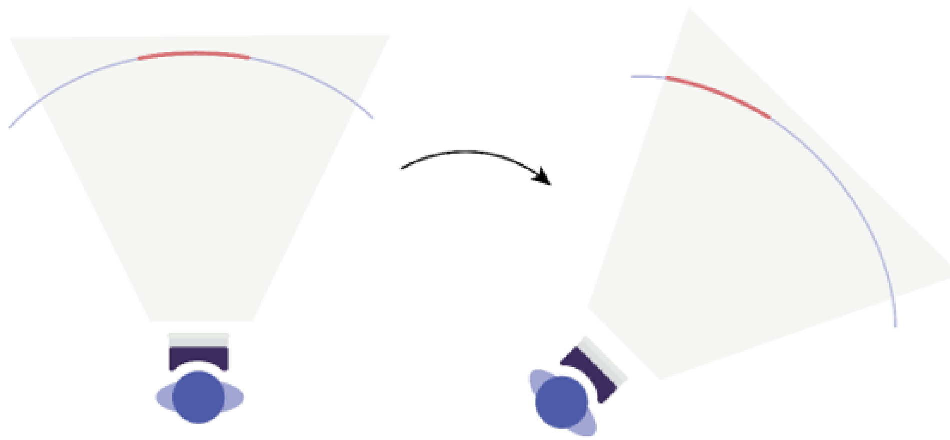

Figure 2: Top view of visual cue movement. The red line in the figure is the task plan. When the chair is rotated to the right, the task plane moves to the opposite direction in the participant's field of vision to give the participant information about the external motion.

2.6 Participants

Twenty-one people participated in the experiment. 11 of them are males and 9 of them are females, and one person is of a third gender. The age ranges from 21 to 28, with an average of 24.2. Participants had different VR and motion sickness experiences, but anyone who had severe motion sickness experience was excluded from further participation.

3 RESULTS

Figure 3 shows the Nausea point of SSQ. The subcategory scores were scaled by the weight factors [8]. The higher score corresponded to a higher sickness level. The result indicates that experimental condition performed well in reducing Nausea and related symptoms. According to the ANOVA, compared with the control condition (24.07), the average score of Nausea in experimental condition (10.44) reduced a lot, this difference is significant ($p = 0.011$).

Figure 4 shows the results of the motion sickness slider. The mean shows the expected increased motion sickness over time. We sampled the value of the participants' slider every 30s.

Compared with the control condition, the average mean of the slider value in experimental condition was reduced from 0.42 to 0.30. According to the ANOVA analysis, this difference is not significant ($p=0.30$).

The results of the SSQ show that our design effectively reduces the symptoms of motion sickness. This study also utilized math questions' correct rate to measure the degree of immersion and productivity quantitively. Compared with the control condition, the correct average rate in the experimental condition was reduced from 98.7% to 97.7%. According to the ANOVA analysis, this difference is not significant ($p=0.41$).

4 DISCUSSION AND FUTURE WORK

In this study, we explored whether the rotation of a rectangular visual interface could serve as an effective visual cue to slow down the development of motion sickness.

Based on the SSQ, the experiment proves that our visual cues have a significant effect on reducing motion sickness-related symptoms. Therefore, our design can be applied to reduce the effects of nausea when using VR in vehicles. Such visual cues are based on existing UIs and do not require additional kinds of visual information. This design potentially has less distraction when users are concentrating. In the meantime, this design's influence on production efficiency is not significant, which means that it created

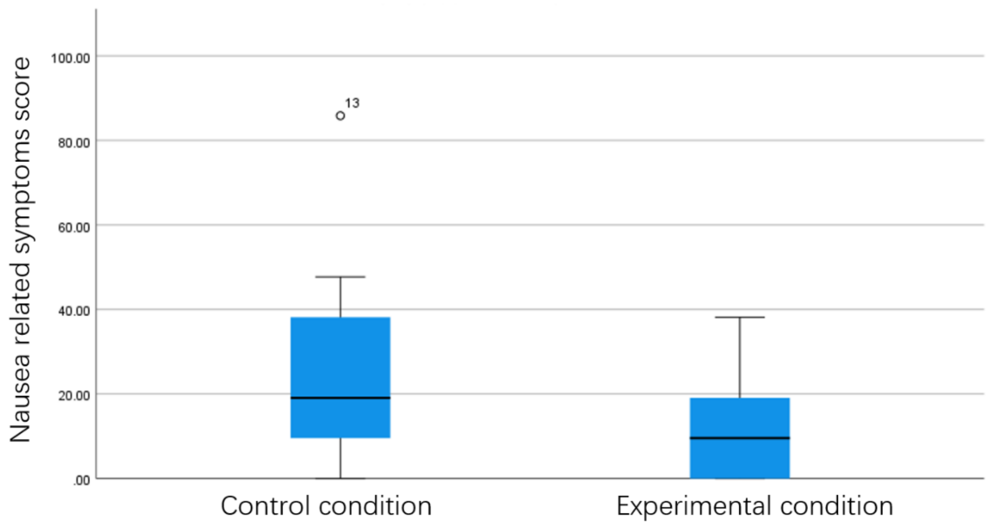

Figure 3: Nausea related symptoms score according to SSQ in control condition and experiment condition.

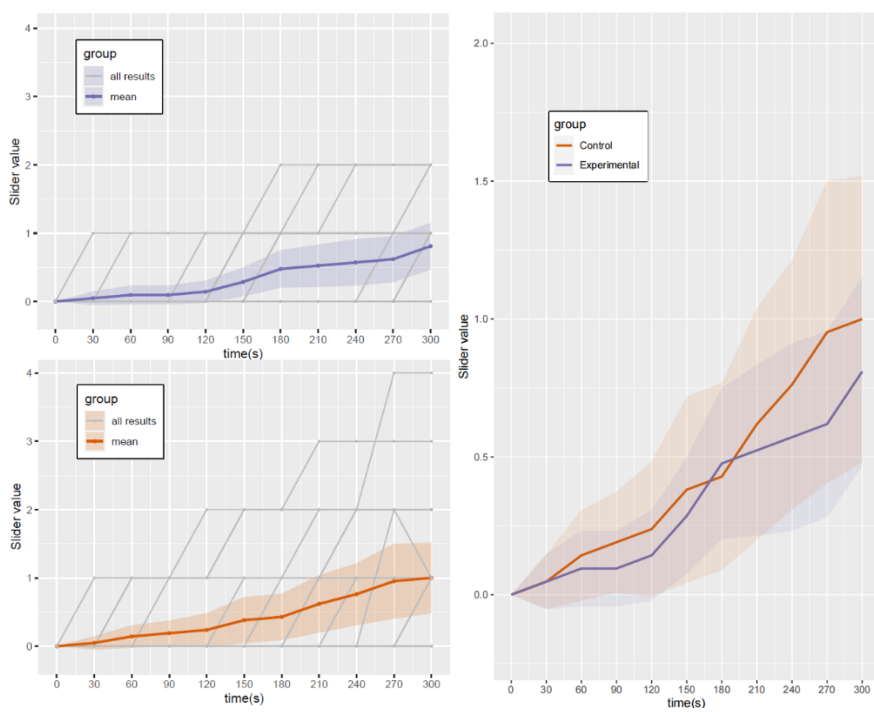

Figure 4: Slider value. The upper left corner is the experimental condition, the lower left corner is the control condition, and the right side is the comparison between the two conditions.

a good balance between reducing motion sickness and preserving participants' immersion level.

There are a few limitations of the experiment. To allow the visual cues to accommodate more kinds of movement, we used the jump-back design after each rotation. According to some participants' feedback, such a design might cause some distractions. We intend to overcome the limitation in our future experiments. Using a more rational jump-back design, may contribute to future research.

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