Can Visual Motion Presented in a VR Headset Reduce Motion Sickness for Vehicle Passengers?

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ABSTRACT

To make the rise of automated vehicles possible and to allow for their mass adoption, one major problem still needs to be solved: Motion sickness. Automated vehicles lead to increased motion sickness partly caused by an occlusion of the outside world (conflict between visual and vestibular system). In this study, we propose the usage of Virtual Reality (VR) headsets for productivity tasks while traveling as well as a motion sickness mitigation strategy. Car motion is simulated using a rotating chair while a reading task is presented in VR with or without visual motion cues being presented in the background. Visual motion cues showed a somewhat beneficial effect on motion sickness in this study without being perceived as too distracting from the primary reading task or affecting reading performance further highlighting the potential of VR usage in transport.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**.

KEYWORDS

Motion Sickness; Virtual Reality; Automated Vehicles; Rotating Chair; Mitigation; Visual Motion

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1 INTRODUCTION

Motion sickness is a common adverse side effect of most forms of transport and is expected to become even more prevalent in automated vehicles [5, 8, 12, 29]. The rise of automated vehicles will lead to a driverless future in which passengers will spend their time traveling engaged in non-driving related tasks (working, reading, watching movies, etc.). The car interior will also be redesigned to better fit the needs of passengers, potentially occluding the view of the external world.

These changes are likely to provoke and increase motion sickness while traveling. The primary cause of motion sickness is a mismatch of information regarding self-motion perceived from sensory systems (e.g., visual and vestibular system; [24, 25]). Engaging in non-driving related tasks and the redesign of the car interior results in no or very limited visual motion cues being perceived, while often strong physical self-motion cues are present [8, 13].

We propose the use of Virtual Reality (VR) headsets to mitigate motion sickness. VR headsets in automated vehicles can serve a dual purpose: They can, for example, be used to perform productivity tasks (e.g., working using multiple screens) allowing the passenger to experience a limitless virtual environment in a physically restricted space [17, 18, 20, 31]; and they can be used to display visual motion cues congruent with the physically perceived car motion to mitigate motion sickness.

Presenting visual motion cues providing additional information about car motion has been shown to reduce motion sickness [4, 9, 16, 19], with some finding no effects on motion sickness [6], possibly due to the type and location of the visual motion cues or due to mitigating effects of attentional and cognitive demands of performed tasks [1, 32].

The current study built on this existing literature by presenting congruent visual motion in VR in combination with a reading task. To investigate how effective visual motion cues are in reducing motion sickness when presented in combination with a cognitive task. This task was chosen to represent a typical non-driving related productivity activity performed during a journey. The type of visual motion cues presented and their location was chosen to elicit the strongest sensation of self-motion possible. Using a *realistic* city landscape rather than abstract optic flow patterns [26–28], presenting the visual motion in the background behind a central display [11, 21, 22, 30] and focusing on the peripheral presentation of the motion cue [3, 7, 11, 23].

Based on this we investigate the following research questions:
R1: Is peripheral presentation of a visual motion stimulus enough to reduce motion sickness or is full field of view (FOV) stimulation more effective?
R2: Are stimuli covering a larger part of the FOV perceived as more distracting from the primary task and does this affect task performance?
R3: Does motion sickness have an effect on task performance ?

2 METHOD

2.1 Participants

Thirty participants took part in this experiment. Data from two participants were excluded due to technical issues during recording. Data from an additional four participants were excluded from the analysis as they experienced no motion sickness in any of the sessions. This resulted in a final sample size of 24 participants of which 10 identified as male and 14 as female, ranging in age from 18 to 34 years.

Figure 1: RotoVR Chair and Participant Set Up

2.2 Experimental Setup

Participants were seated on a rotating chair (*RotoVR* (https://www.rotovr.com); see Figure 1) which performed *Yaw* rotations while they wore a Vive Focus 3 VR headset (www.vive.com). The movements performed by the chair (degree and speed of rotation) were based on a urban city drive (see Figure 2); with these predefined motions presented for the duration of a 15 minute trial. The virtual environment surrounding the participants consisted of a city landscape in the background and a display presenting a reading task in the foreground centred in front of them (see Figure 3). Reading is a common task performed by passengers in vehicles and can be affected by motion sickness. The selected articles were presented to participants 20 words at a time to ensure legibility whilst constraining the text to central vision only. Participants were told that they might be asked questions about the articles after the session to encourage active reading.

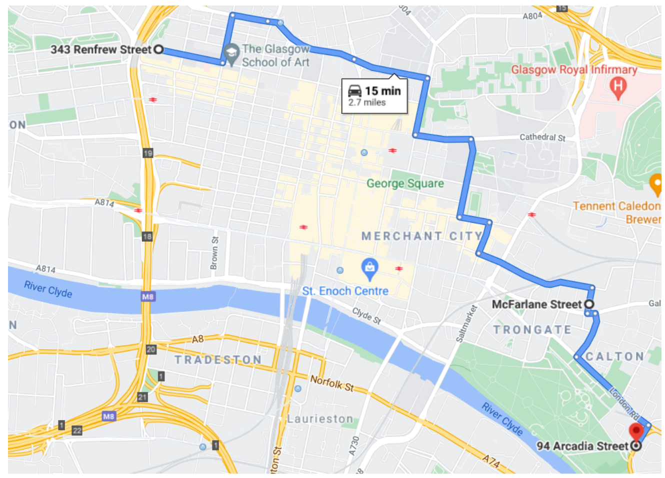


Figure 2: Route - Urban City Drive

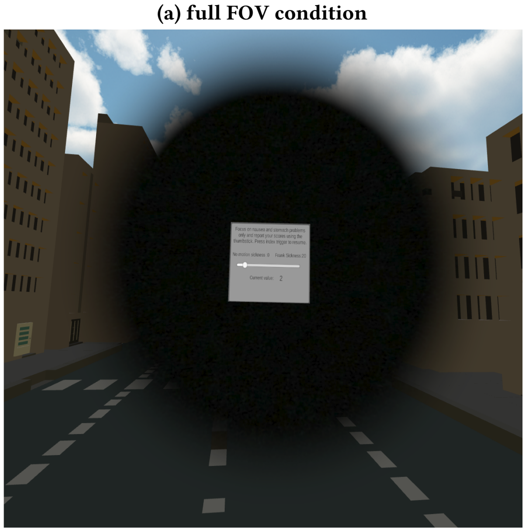
To answer the research questions, two baseline and two experimental conditions were designed: (1) *Baseline No-Motion condition*: This condition is expected to cause none or very weak motion sickness as neither physical (chair) nor visual (city scene) motion is presented. (2)*Baseline Motion condition*: This condition is expected to cause most motion sickness due to the strongest conflict between vestibular and visual system. The chair is rotating while the visually presented city scene is stationary. (3)*Full FOV condition*: Congruent visual and physical motion are presented. The visual motion is visible in the entire FOV in the background. (4)*Partial FOV condition*: Congruent visual and physical motion is presented. The visual motion is visible in the peripheral FOV only, with the central half of the visual field (30 degrees) being occluded (see Figure 3). Conditions were presented on separate days to avoid carry over and accumulative effects of motion sickness.

2.3 Measures

Motion Sickness: The Misery Scale (MISC, [2]) served as a continuous measure. Participants rated their level of motion sickness every minute. The Simulator Sickness Questionnaire (SSQ, [14]) served as an overall measure of motion sickness. Participants filled this out before and after each condition.

Perception of VR Environment: We were interested how changes in the virtual environment affect an individual's perceived mental demand of the task and how distracting they perceive the environment to be. Mental demand was measured using the NASA-TLX

(a) full FOV condition



(b) Partial FOV condition

Figure 3: Example of the (a) full FOV and (b) partial FOV conditions. Including an example of the Motion Sickness Scale and the Reading task

scale ([10]) while the level of distraction of the environment was rated on a 5-point Likert scale.

Reading Speed: We were also interested whether the changes in the environment or motion sickness had an effect on individual's reading performance,therefore, recording participants reading speed. A selection of news articles was chosen for this.

3 RESULTS

3.1 Motion Sickness

3.1.1 MISC Ratings. A linear mixed effect model showed a significant effect of condition on MISC ratings, F(3,69) = 3.52, p= .02, f^2 = .13. *Post hoc* tests revealed that the Baseline Motion condition (M = 2.09, SD = 2.37) caused significantly more motion sickness compared to the Baseline No-Motion condition (M = 0.91, SD = 1.73, t(69)= 3.06, p = .016, d = .56). None of the other comparisons were significant.

3.1.2 SSQ Scores. A significant effect of condition on SSQ scores was found, F(3,69) = 3.77, p= .014, f^2 = .13. *Post hoc* tests revealed that the Baseline Motion condition (M = 22.60, SD = 24.38) caused significantly higher SSQ scores compared to the Baseline No-Motion condition (M = 7.01, SD = 15.07, t(69)= 3.24, p = .010, d = .77). None of the other comparisons were significant.

3.2 Perception of the VR Environment

3.2.1 Mental Demand. No significant effect of condition on NASA TLX scores was found, F(3,69) = 1.18, p= 0.324.

3.2.2 Distraction. Condition had a significant effect on how distracting the VR environment was, F(3,69) = 3.29, p= .026, f^2 = .12. The Full FOV condition (M = 3.96, SD = 0.84) was perceived as significantly more distracting compared to the Baseline No-Motion condition (M = 3.17, SD = 0.76, t(69)= 2.82, p = .031, d = .56). None of the other comparisons were significant, see Figure 4c.

3.3 Reading Speed

3.3.1 Environment. : Condition had a significant effect on reading speed, F(3, 69) = 3.88, p = . 013, f^2 = .12. *Post hoc* analysis revealed that participants read significantly faster in the Baseline Motion condition (M = 147.79 pages, SD = 49.40 pages) compared to the Baseline No-Motion condition (M =133.92 pages, SD = 38.54 pages), t(69) = 3.23, p = .010, d = .31 . Neither Partial FOV (M = 143.21 pages, SD = 43.47 pages) nor Full FOV condition (M = 138.54 pages, SD = 43.47 pages) differed significantly from either baseline condition or from each other.

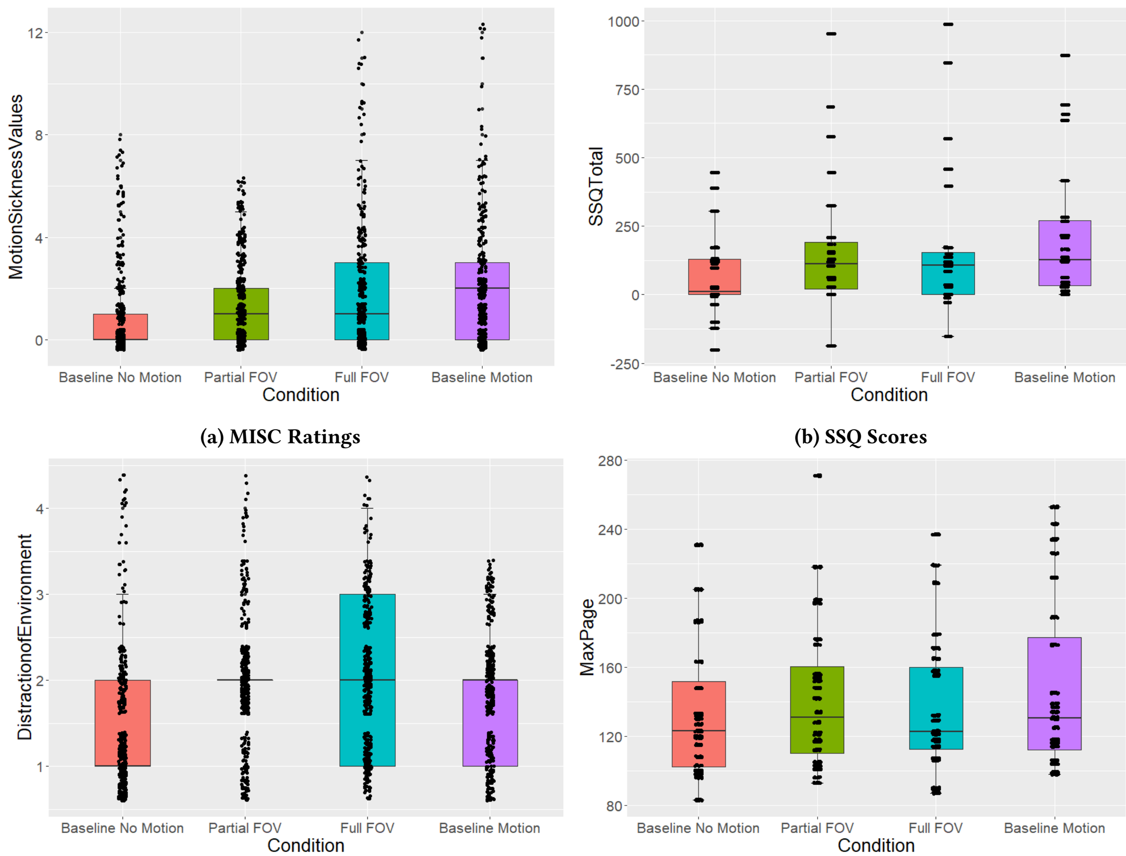
3.3.2 Motion Sickness. : MISC ratings had a significant effect on reading speed, F(1,76) = 6.21, p= .015, f^2 = .03. Participants read around 4.2 words more with each increase in MISC rating.

4 DISCUSSION

This study investigated the suitability of VR headsets to mitigate motion sickness by presenting visual motion cues matched to rotations during a reading task. The results show that while performing *city driving motions* the rotating chair was able to induce mild motion sickness (Baseline No-Motion vs. Baseline Motion condition), suggesting it is a good platform for motion sickness research. There also seemed to be some beneficial effects on motion sickness for visual motion cues in VR. The conditions in which visual motion was present did not differ significantly in motion sickness from the Baseline Motion condition (strongest motion sickness) nor from the Baseline No-Motion condition (weakest motion sickness).

Motion sickness experienced throughout the experiment was rather low which could partially explain the non-significant findings in this study. We expect that if moderate or severe motion sickness is induced by the chair (either through longer duration of city-type driving; or through more extreme motion) visual motion cues would have a more severe effect on motion sickness mitigation.

Presenting the visual motion cues in the full FOV was experienced as more distracting compared to no visual motion being



(a) MISC Ratings **(b) SSQ Scores**

(c) Distraction of VR Environment **(d) Reading Speed**

Figure 4: Predicted (a) Motion Sickness, (b) SSQ Scores, (c) Distraction of the VR Environment and (d) Reading Speed for the Baseline No-Motion, Partial FOV, Full FOV and Baseline Motion conditions.

present. However, this seemed to have no effect on the task performance (reading speed). Therefore, suggesting that using visual motion cues while individuals are engaged in non-driving related tasks is a suitable method to reduce motion sickness as they do not affect perceived mental demand or task performance. Results also suggest that presenting visual motion in the periphery only is sufficient in reducing motion sickness while not distracting from the primary task.

Motion sickness affected reading speed, with participants reading faster with increases in motion sickness. In this experimental design, even though participants believed that they would be asked questions about the articles after the sessions, we cannot say with certainty whether participants were actively reading the articles presented to them or whether they were passively skipping through them and when experiencing motion sickness increasing the speed in an attempt to end the experiment sooner.

4.1 Implications and Future Work

Our findings show that visual stimuli presented in VR can be used to reduce motion sickness experienced in automated vehicles. Including them in a large part of the visual field will result in the environment being perceived as more distracting, which however, does not seem to affect reading performance. A visually distracting environment could, however, affect performance on other types of cognitive tasks , for example, involving visuo-spatial attention. Underlying the importance of identify a visual stimulus that is able to mitigate motion sickness without being too distracting. Motion sickness affects reading speed resulting in faster reading, which we believe to reflect less active reading and comprehension of the text. Presenting visual motion stimuli in the periphery only might be most suitable for motion sickness mitigation without distracting from a primary cognitive task (e.g., working, reading).

In a follow-up experiment we will induce stronger motion sickness by increasing the duration of the session [15] and by introducing faster turns and speeds. We predict that if stronger motion sickness is experienced by participants, additional sensory cues giving information about their self-motion should have stronger effects on motion sickness reduction. We will change the reading task to include reading comprehension allowing us to ensure participants are actively reading and comprehending, and to further investigate the effect of motion sickness on cognitive performance.

4.2 Conclusion

In conclusion, this work demonstrated the potential for VR for motion sickness mitigation in automated vehicles. We demonstrated that peripheral presentation of a visual motion is as effecting in reducing motion sickness as full FOV presentation. This is important as it allows more of the visual field to be occupied by a primary task, for example allowing individuals to display multiple screen for work. This work further builds a foundation for future laboratory as well as on-road research investigating the potential of visual motion cues for motion sickness mitigation.

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REFERENCES

[1] Jelte E Bos. 2015. Less sickness with more motion and/or mental distraction. *Journal of Vestibular Research* 25, 1 (2015), 23–33.
[2] Jelte E Bos, Scott N MacKinnon, and Anthony Patterson. 2005. Motion sickness symptoms in a ship motion simulator: effects of inside, outside, and no view. *Aviation, space, and environmental medicine* 76, 12 (2005), 1111–1118.
[3] Th Brandt, Johannes Dichgans, and Ellen Koenig. 1973. Differential effects of central versus peripheral vision on egocentric and exocentric motion perception. *Experimental brain research* 16, 5 (1973), 476–491.
[4] Hyung-Jun Cho and Gerard J Kim. 2022. RideVR: Reducing Sickness for In-Car Virtual Reality by Mixed-in Presentation of Motion Flow Information. *IEEE Access* 10 (2022), 34003–34011.
[5] Abhraneil Dam and Myounghoon Jeon. 2021. A Review of Motion Sickness in Automated Vehicles. In *13th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. 39–48.
[6] Ksander N de Winkel, Paolo Pretto, Suzanne AE Nooij, Iris Cohen, and Heinrich H Bülthoff. 2021. Efficacy of augmented visual environments for reducing sickness in autonomous vehicles. *Applied Ergonomics* 90 (2021), 103282.
[7] André Delorme and Christian Martin. 1986. Roles of retinal periphery and depth periphery in linear vection and visual control of standing in humans. *Canadian Journal of Psychology/Revue canadienne de psychologie* 40, 2 (1986), 176.
[8] Cyriel Diels and Jelte E Bos. 2016. Self-driving carsickness. *Applied ergonomics* 53 (2016), 374–382.
[9] PJ Feenstra, Jelte E Bos, and Ronald NHW van Gent. 2011. A visual display enhancing comfort by counteracting airsickness. *Displays* 32, 4 (2011), 194–200.
[10] Sandra G Hart and Lowell E Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in psychology*. Vol. 52. Elsevier, 139–183.
[11] Ian P Howard and Thomas Heckmann. 1989. Circular vection as a function of the relative sizes, distances, and positions of two competing visual displays. *Perception* 18, 5 (1989), 657–665.
[12] Julie Iskander, Mohammed Attia, Khaled Saleh, Darius Nahavandi, Ahmed Abobakr, Shady Mohamed, Houshyar Asadi, Abbas Khosravi, Chee Peng Lim, and Mohammed Hossny. 2019. From car sickness to autonomous car sickness: A review. *Transportation research part F: traffic psychology and behaviour* 62 (2019), 716–726.
[13] Monica LH Jones, Victor C Le, Sheila M Ebert, Kathleen H Sienko, Matthew P Reed, and James R Sayer. 2019. Motion sickness in passenger vehicles during test track operations. *Ergonomics* 62, 10 (2019), 1357–1371.
[14] 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, 3 (1993), 203–220.
[15] Robert S Kennedy, Kay M Stanney, and William P Dunlap. 2000. Duration and exposure to virtual environments: sickness curves during and across sessions. *Presence: Teleoperators & Virtual Environments* 9, 5 (2000), 463–472.
[16] Ouren X Kuiper, Jelte E Bos, and Cyriel Diels. 2018. Looking forward: In-vehicle auxiliary display positioning affects carsickness. *Applied Ergonomics* 68 (2018), 169–175.
[17] Mark Mcgill, Aidan Kehoe, Euan Freeman, and Stephen Brewster. 2020. Expanding the bounds of seated virtual workspaces. *ACM Transactions on Computer-Human Interaction (TOCHI)* 27, 3 (2020), 1–40.
[18] Mark McGill, Gang Li, Alex Ng, Laura Bajorunaite, Julie Williamson, Frank Pollick, and Stephen Brewster. 2022. Augmented, Virtual and Mixed Reality Passenger Experiences. In *User Experience Design in the Era of Automated Driving*. Springer, 445–475.
[19] Mark McGill, Alexander Ng, and Stephen Brewster. 2017. I am the passenger: how visual motion cues can influence sickness for in-car VR. In *Proceedings of the 2017 chi conference on human factors in computing systems*. 5655–5668.
[20] Mark McGill, Julie Williamson, Alexander Ng, Frank Pollick, and Stephen Brewster. 2020. Challenges in passenger use of mixed reality headsets in cars and other transportation. *Virtual Reality* 24, 4 (2020), 583–603.
[21] Shinji Nakamura. 2006. Effects of depth, eccentricity and size of additional static stimulus on visually induced self-motion perception. *Vision Research* 46, 15 (2006), 2344–2353.
[22] Shinji Nakamura and Shinsuke Shimojo. 1999. Critical role of foreground stimuli in perceiving visually induced self-motion (vection). *Perception* 28, 7 (1999), 893–902.
[23] Katharina Margareta Theresa Pöhlmann, Julia Föcker, Patrick Dickinson, Adrian Parke, and Louise O'Hare. 2021. The effect of motion direction and eccentricity on vection, VR sickness and head movements in virtual reality. *Multisensory Research* 34, 6 (2021), 623–662.
[24] James T Reason. 1978. Motion sickness adaptation: a neural mismatch model. *Journal of the Royal Society of Medicine* 71, 11 (1978), 819–829.
[25] James T Reason and Joseph John Brand. 1975. *Motion sickness*. Academic press.
[26] Bernhard E Riecke. 2011. Compelling self-motion through virtual environments without actual self-motion: using self-motion illusions ("vection") to improve user experience in VR. *Virtual reality* 8, 1 (2011), 149–178.
[27] Bernhard E Riecke, Jörg Schulte-Pelkum, Marios N Avraamides, Markus Von Der Heyde, and Heinrich H Bülthoff. 2006. Cognitive factors can influence self-motion perception (vection) in virtual reality. *ACM Transactions on Applied Perception (TAP)* 3, 3 (2006), 194–216.
[28] Bernhard E Riecke, Daniel Västfjäll, Pontus Larsson, and Jörg Schulte-Pelkum. 2005. Top-down and multi-modal influences on self-motion perception in virtual reality. In *Proceedings of HCI international 2005*. 1–10.
[29] Spencer Salter, Doug Thake, Stratis Kanarachos, and Cyriel Diels. 2019. Motion sickness prediction device for automated vehicles. *International Journal of Mechanical and Production Engineering* 7, 2 (2019), 68–74.
[30] Takeharu Seno, Hiroyuki Ito, and Shoji Sunaga. 2009. The object and background hypothesis for vection. *Vision research* 49, 24 (2009), 2973–2982.
[31] Graham Wilson, Mark McGill, Matthew Jamieson, Julie R Williamson, and Stephen A Brewster. 2018. Object manipulation in virtual reality under increasing levels of translational gain. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–13.
[32] Celina Zhou, Clara Luisa Bryan, Evan Wang, N Sertac Artan, and Ziqian Dong. 2019. Cognitive distraction to improve cybersickness in virtual reality environment. In *2019 IEEE 16th International Conference on Mobile Ad Hoc and Sensor Systems Workshops (MASSW)*. IEEE, 72–76.