Predicting Cybersickness Susceptibility from Gaze Behavior

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ABSTRACT

We investigate whether differences in gaze behavior are correlated with stronger field dependence and the tendency to experience cybersickness sooner in virtual reality. Participants experienced a 30-minute roller coaster designed to induce cybersickness. Participants were asked to align two dots vertically while eye-tracking was collected. The results suggest that participants with stronger field dependence tended to focus more on the background and peripheral scenery, experienced greater sensory conflict, and dropped out sooner than those with more field-independent patterns of gaze. These findings point to a potential correlation between gaze strategies, field dependence, and cybersickness, motivating further analysis of gaze metrics as a predictive tool.

Index Terms: Human-centered computing—Human Computer Interaction (HCI)—Interaction paradigms—Virtual reality; Human-centered computing—HCI design and evaluation methods—User models

1 INTRODUCTION AND BACKGROUND

Cybersickness, a form of visually induced motion sickness, is one of the main barriers to the long-term use of immersive technologies. It is considered a form of motion sickness with symptoms and physiological changes similar to sickness in cars, space, and other simulators. Cybersickness is widely thought to result from a mismatch between vestibular and visual cues, which creates conflicting sensory signals and leads to symptoms [4, 6]. Individual differences such as experience with VR, susceptibility to classical motion sickness, age, and visual sensitivity have been observed to influence cybersickness severity [3]. Understanding the role of individual differences can allow specific mitigation techniques and experiences for different groups.

We report an exploratory study investigating whether cybersickness susceptibility is linked to gaze patterns during the Rod and Frame test in virtual reality (VR). We ask if field dependence can be detected from gaze behavior and whether these patterns relate to how quickly someone becomes too sick to continue a VR session.

The field dependence/independence construct was initially conceptualized by Witkin et al. [9] to describe an individual's tendency to rely more on visual or gravitational cues. A standard test to measure field dependence is the Rod and Frame Test (RFT). The original RFT asks participants to vertically align a rod enclosed by a tilted frame. This provides a controlled measure of how individuals allocate attention between task-relevant and background cues. These tendencies may extend to more natural VR experiences, such as roller coasters, where field-dependent (FD) users may rely on peripheral scenery, creating a greater sensory conflict and increasing the risk of cybersickness. Field-independent (FI) individuals are able to align the rod to the true vertical, while FD individuals tend to be more strongly influenced by the frame tilt [8]. Recent studies [5] found that the scores from the RFT can explain a significant part of the variance in cybersickness.

Our motivation is to understand the role of gaze behavior in cybersickness, particularly as it relates to field dependence. FD individuals may rely more on background cues, creating larger sensory conflicts and triggering symptoms sooner. We hypothesize that participants with stronger field dependence will show distinct gaze patterns, such as spending more time looking at their surroundings. These gaze patterns, combined with field dependence, will help explain why some participants experience stronger and earlier symptoms of cybersickness during VR experiences.

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2 METHODS

To investigate our hypothesis, we presented a cybersickness-inducing stimulus for 30 minutes or until participants dropped out. The experimental protocol was approved by Northeastern University Institutional Review Board (#23-04-17). Informed consent was obtained prior to the start of the study. Participants in the study had the chance to receive a $50 gift card (odds 1:9).

To measure field dependence, we used a VR version of the RFT. Participants viewed two dots representing the ends of a rod in an empty room that was tilted around the viewing axis. Participants would then rotate the rod until they believed it was perfectly vertical, regardless of the rotation of the room. Individuals who are more influenced by the tilted frame are considered more FD, while those who can ignore the background and align the rod accurately are more FI. During the test, we recorded participants' gaze direction as they aligned the rod. Each gaze sample was cast into the 3D rod-and-frame environment to find which object the participant's gaze intersected with (rod versus background elements). These gaze targets were then used to calculate the percentage of time looking at the rod compared to other areas of the scene. We also recorded the amplitude of the error of aligning with the vertical.

To induce cybersickness, we used a VR roller coaster stimulus as in previous studies [7]. Each participant completed up to five sessions of three rides (max 15 rides), with each ride lasting two minutes, using the same track for consistency.

The experimental application was developed using Unity 3D engine 2021.3.15f1 and presented in the HTC VIVE Pro Eye VR headset connected to desktop. Participants interacted using the Vive standard controllers.

3 RESULTS

We found that participants spent a small percentage of the time looking at the foreground (min:0.01, median: 0.59, mean:1.29, max:7.74). Figure 1 shows the 2D projection of gaze intersection points during the RFT. Each dot represents a location in the virtual environment where a participant's gaze ray intersected with the scene while they were aligning the rod, and each color corresponds to a different participant. The circular pattern reflects the edges of the tilted frame, with denser clusters along the frame edges and around the central rod. This visualization highlights that, while all participants looked at the rod, there were differences in how broadly they scanned the background and frame during the task.

To further quantify these gaze differences, we computed the percentage of time each participant spent looking directly at the rod versus other areas of the display. Figure 2 shows the distribution

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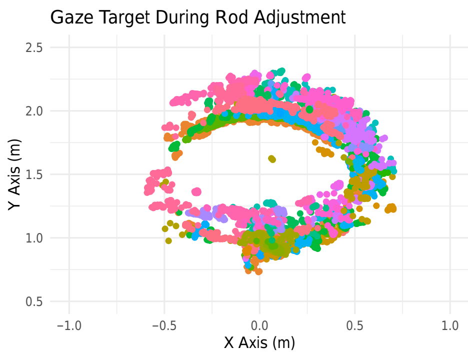

Figure 1: 2D projection of gaze points during the rod-and-frame task. Colors mark participants. Clusters around the circle correspond to the frame, and central points to fixations on the rod.

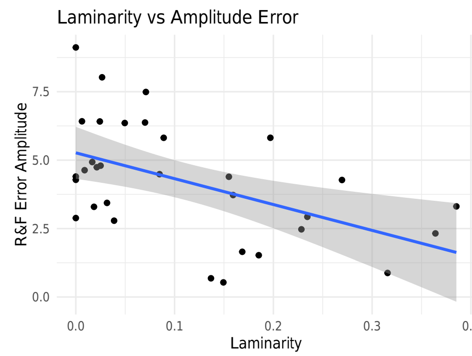

Figure 3: Laminarity vs Amplitude Error. The blue line is a linear regression fit.

of these percentages for FD and FI participants generally spent a higher proportion of their gaze on the rod, while FD participants allocated slightly more attention to the surrounding frame and background. These results suggest that FD participants allocated a greater proportion of their gaze to background elements compared to FI participants, who concentrated more on the task-related objects directly in front of them.

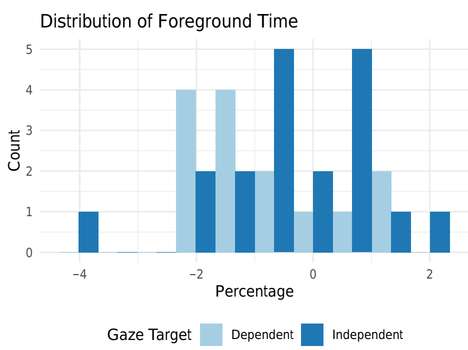

Figure 2: Distribution of gaze time on the rod. Light bars: field-dependent; dark bars: field-independent. Field-dependent participants spent less time fixating on the rod, scanning more of the frame/background.

Following Anderson et al. [1] we conducted a Recurrence Quantification Analysis (RQA) of the gaze data of each participant. RQA is a non-linear dynamical systems technique used to characterize complex systems. RQA can determine when a system returns to a previously visited state by comparing the similarity between time series at every possible time lag. We computed a metric known as Laminarity (LAM) using the R package NonLinearTSeries [2]. Figure 3 plots Laminarity vs the Rod and Frame Amplitude Error.

We conducted a linear regression to examine the relationship between LAM and AmplitudeE. The model was statistically significant, $F(1,30) = 10.09$, $p = .003$, and explained approximately 25% of the variance in AmplitudeE ($R^2 = .25$, adjusted $R^2 = .23$). We found that LAM significantly predicted AmplitudeE, $\beta = -9.45$, $t(30) = -3.18$, $p = .003$. This suggests that higher laminarity values are associated with lower AmplitudeE values.

For future work, we will extend these analyses by applying RQA to find other metrics that have been shown useful to characterize eye movements (e.g., determinism, recurrence) in order to fully investigate their ability to detect propensity to cybersickness.

4 Conclusion

These results highlight a connection between gaze patterns, field dependence, and susceptibility to cybersickness in VR. Participants who were more FD distributed their attention more broadly across the environment, which was associated with an earlier onset of cybersickness. Moving forward, we will apply RQA to our eye-tracking data to quantify the temporal structure of gaze behavior using measures such as recurrence, determinism, and laminarity. These metrics will provide a deeper understanding of how viewing strategies and field dependence interact and may eventually help identify individuals at greater risk for cybersickness. To our knowledge, this is the first work to combine gaze measures from the RFT with recurrence-based eye-movement analysis in this context. Identifying gaze behavior as a predictor of vulnerability could ultimately support the development of VR systems that adaptively adjust content to make VR more comfortable for each user.

References

[1] N. C. Anderson, W. F. Bischof, K. E. W. Laidlaw, E. F. Risko, and A. Kingstone. Recurrence quantification analysis of eye movements. *Behavior research methods*, 45(3):842–56, Sep 2013. doi: 10.3758/s13428-012-0299-5

[2] C. A. Garcia. *nonlinearTseries: Nonlinear Time Series Analysis*, 2024. R package version 0.3.1. doi: 10.32614/CRAN.package.nonlinearTseries

[3] A. Maneuvrier, L. M. Decker, H. Ceyte, P. Fleury, and P. Renaud. Presence promotes performance on a virtual spatial cognition task: Impact of human factors on virtual reality assessment. *Frontiers in Virtual Reality*, 1:571713, 2020.

[4] A. Maneuvrier, L. M. Decker, P. Renaud, G. Ceyte, and H. Ceyte. Field (in) dependence flexibility following a virtual immersion is associated with cybersickness and sense of presence. *Frontiers in Virtual Reality*, 2:706712, 2021.

[5] A. Maneuvrier, N.-D.-T. Nguyen, and P. Renaud. Predicting vr cybersickness and its impact on visuomotor performance using head rotations and field (in) dependence. *Frontiers in Virtual Reality*, 4:1307925, 2023.

[6] J. T. Reason. Motion sickness adaptation: a neural mismatch model. *Journal of the royal society of medicine*, 71(11):819–829, 1978.

[7] K. Stanney, C. Fidopiastis, and L. Foster. Virtual reality is sexist: but it does not have to be. *Frontiers in Robotics and AI*, 7:4, 2020.

[8] H. A. Witkin and S. E. Asch. Studies in space orientation. iv. further experiments on perception of the upright with displaced visual fields. *Journal of Experimental Psychology*, 38(6):762, 1948.

[9] H. A. Witkin, H. B. Lewis, M. Hertzman, K. Machover, P. B. Meissner, and S. Wapner. Personality through perception: An experimental and clinical study. 1954.