Camera Motion Impacts Cybersickness in Augmented Reality

Henry Kam[1]; Niall L. Williams[1]; Jeffrey Lubin[2]; James R. Bergen[2]; Mikhail Sizintsev[2]; Qi Sun[1]; Colin Groth[1]
[1]New York University, [2]SRI International

Background and Goals

Cybersickness is a challenge that persists in wide field of view, near-eye displays, when visual motion conflicts with vestibular signals. The conflicting visual motion cues in optical see-through augmented reality (OST-AR) headset are overlaid on ground-truth physical world cues, and the resulting interaction effects on sickness are poorly understood.

Prior work:
- Reported minimal amounts of AR sickness after long exposure. [1]
- AR sickness is governed by plane of fixation (physical vs virtual) (prior unpublished work N=20)

We explore:
- How does rotational camera motion impact cybersickness in augmented reality?
- How do we mitigate cybersickness in OST-AR?

Experiment Design

- **Display:** Magic Leap 2 (40˚ H FOV), head-locked rectangular AR viewport centered on display
- **Stimulus:** Virtual concrete rectangular room with red and blue paintings on the walls
- **Task:** Count paintings of a target color; paintings can be temporarily invisible, so passing a previously-occupied location was possible. One white painting was centered as a point of reference.
- **Motion:** Virtual camera oscillated side-to-side (yaw) while participants remained physically seated (visual-vestibular conflict)
- **Perturbation:** Sinusoidal pitch perturbations added on top of rotation, amplitude 5˚ yaw, randomized frequencies within a range
- **Measures:** Fast Motion Sickness (FMS) Score [2] every 45s during exposure, Simulator Sickness Questionnaire (SSQ) [3] pre/post session
- **Session Structure:** 15 min exposure per session, 4 sessions per participant, ≥24h apart to prevent carry-over effects
- **Participants:** N=8 (μ = 23.625, σ = 1.19, 4 M 4 F, same cohort across experiments)

Quantifying Camera Motion and AR Sickness

- **Conditions (within-subject, counterbalanced across 4 sessions):**
  - Rotation speeds: 20˚/s, 30˚/s, 40˚/s (40˚/s is ceiling before smooth-pursuit instability [4])
  - Perturbation frequencies: none, 0.5-1Hz, 1.5-3Hz
  - No perturbations at 40˚/s (combined velocity > pursuit ceiling)

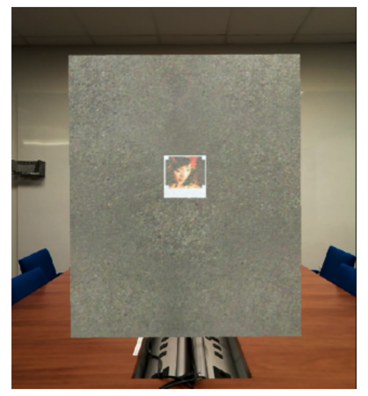
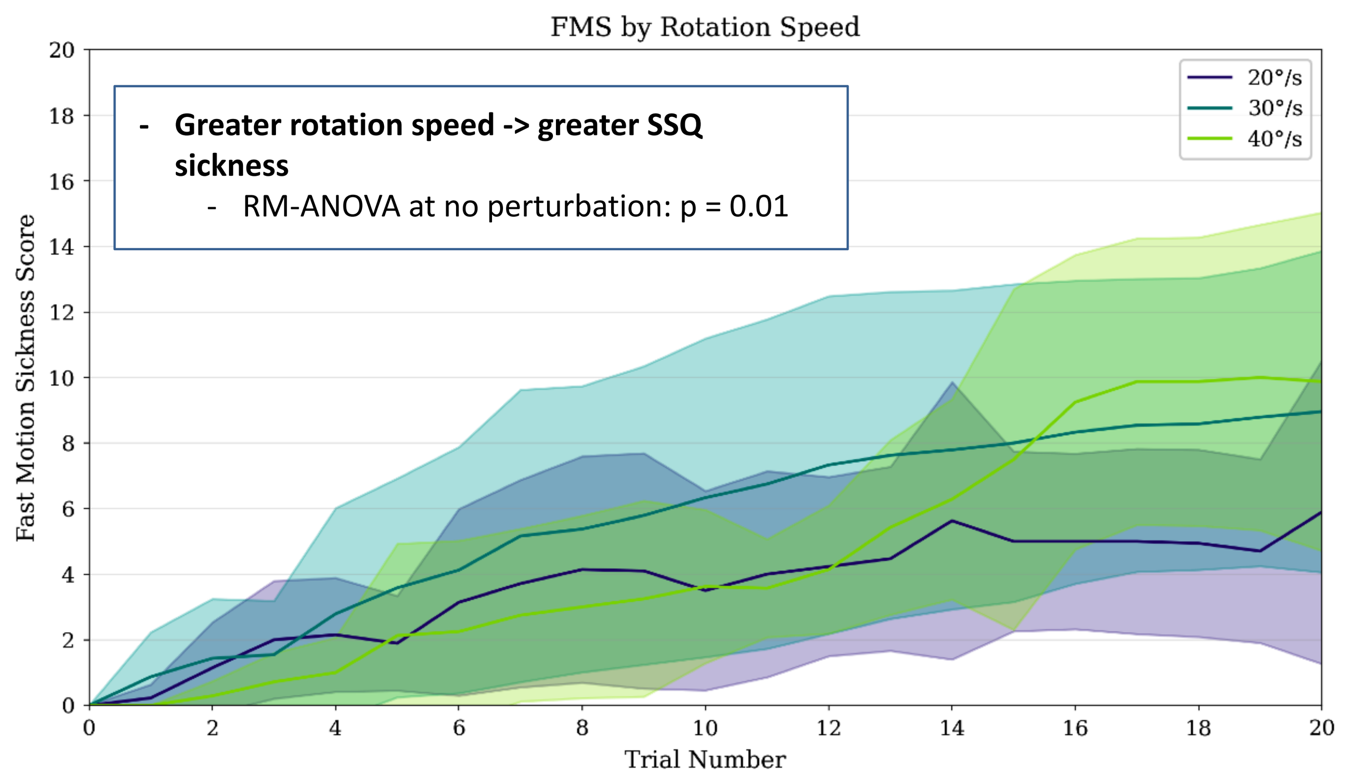
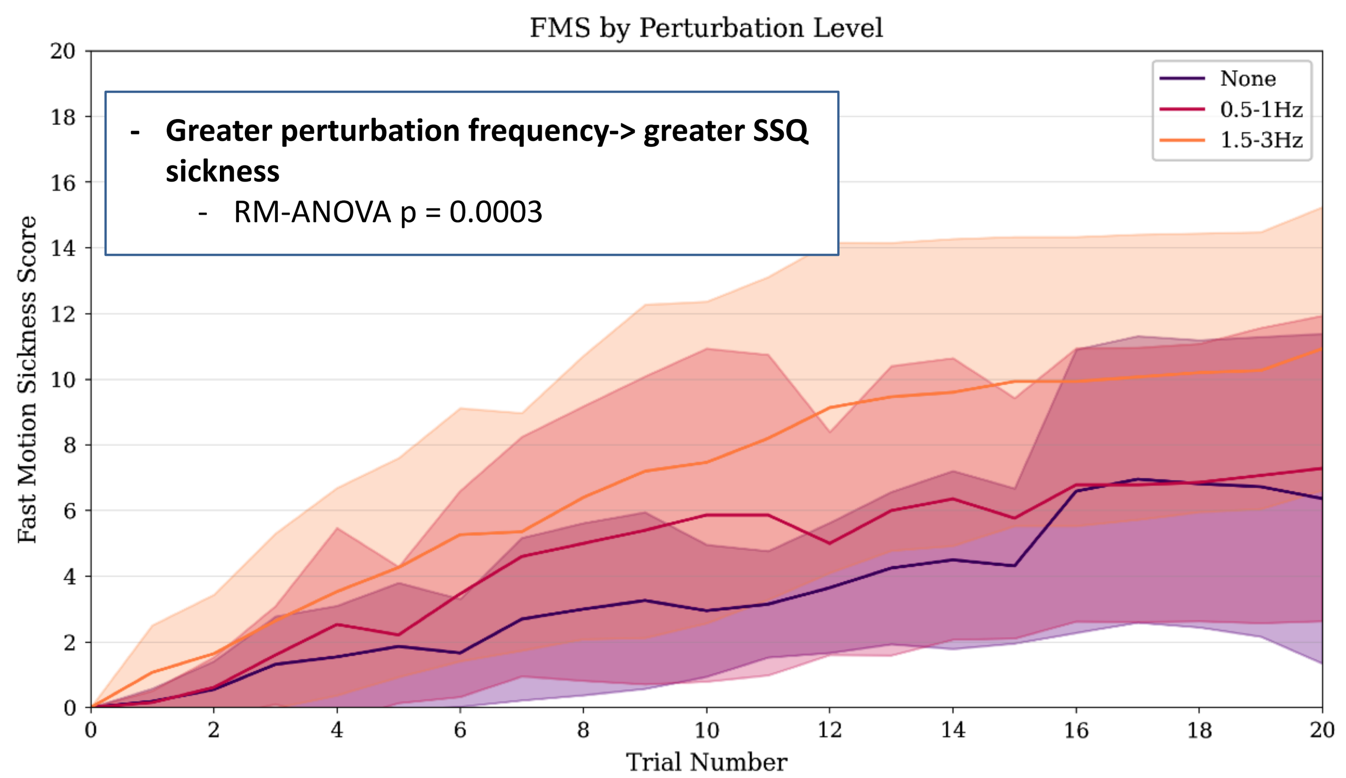


Figure 1. Experiment Stimulus

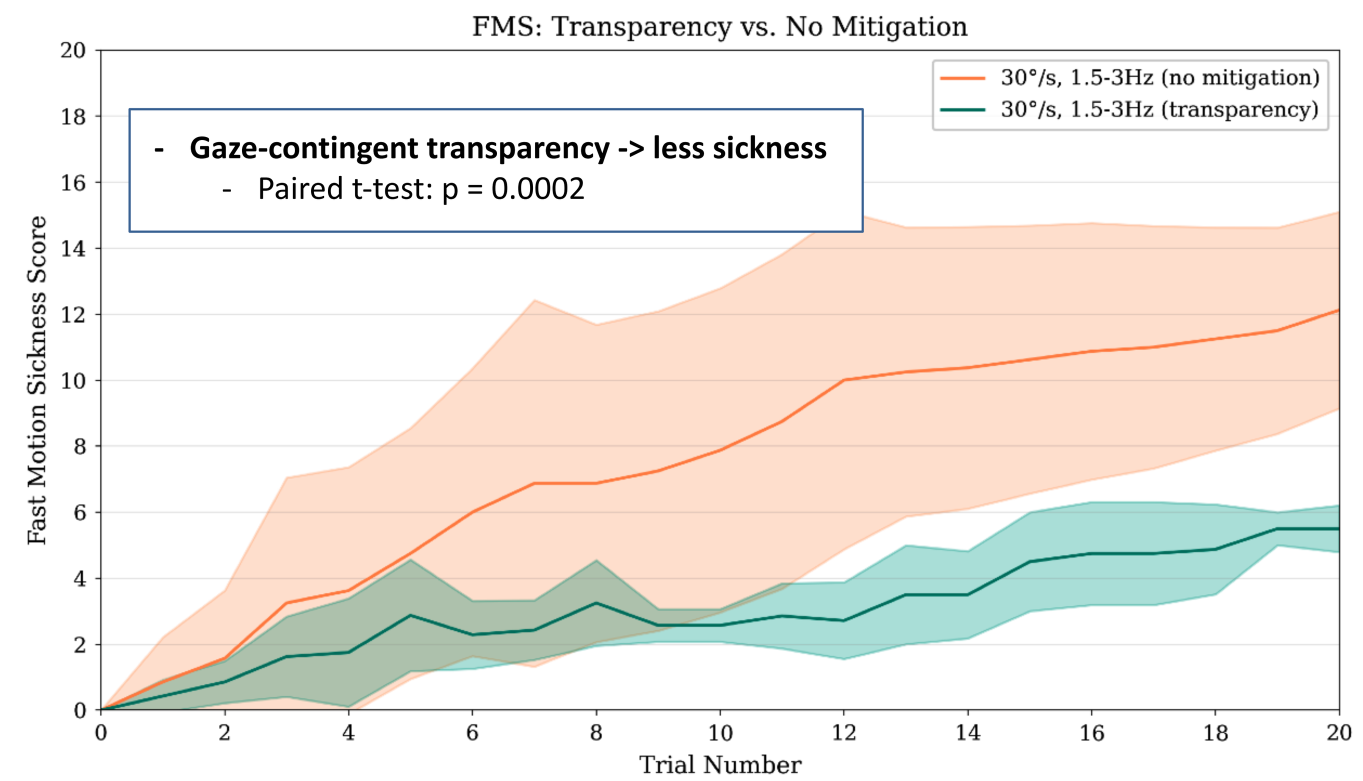
Figure 2. Application of Transparency

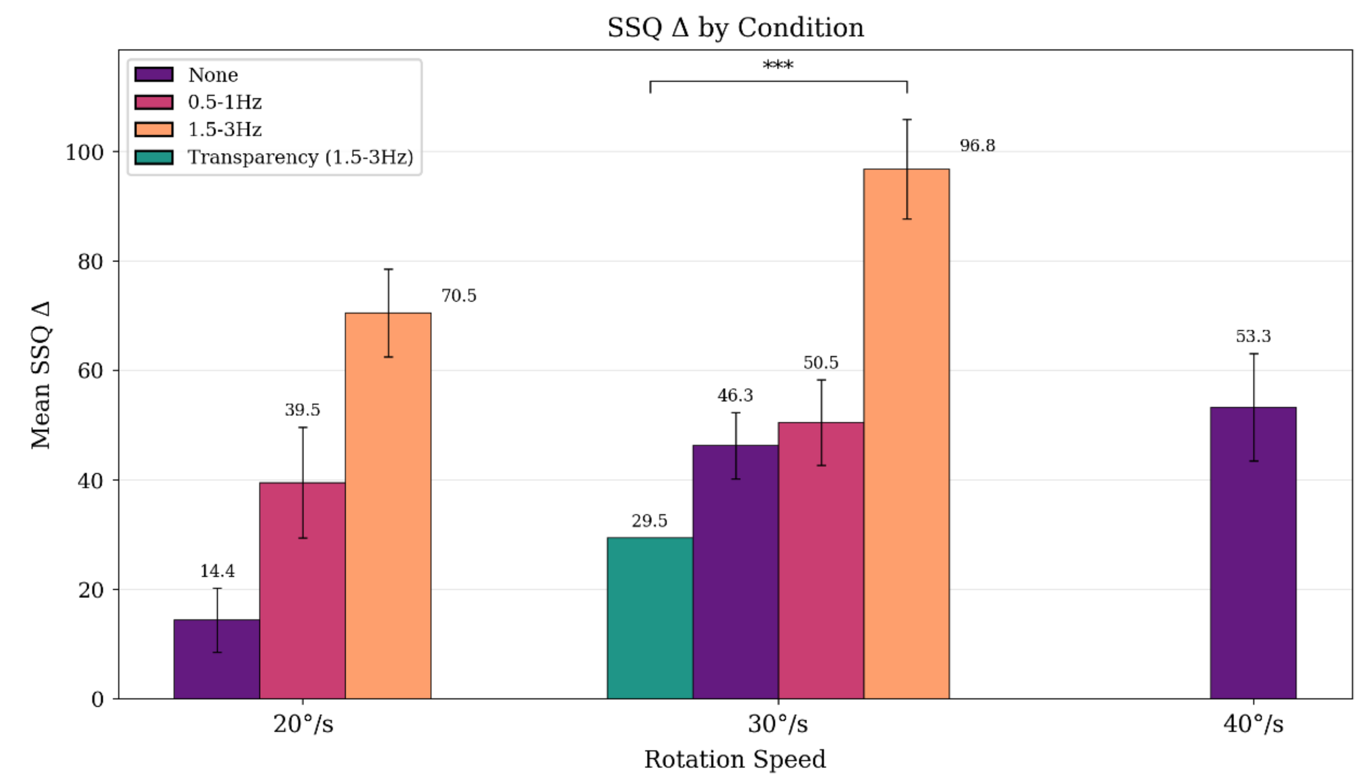




Mitigation: Gaze-Contingent Transparency

- **Rationale:** Vection cues are largely driven by peripheral retinal motion [5]. We hypothesize that increasing peripheral transparency reduces visual vestibular conflict, and as a result, cybersickness. Similar to peripheral blurring in VR [6].
- **Transparency Manipulation**
  - Same stimulus and task, rotation fixed at 30˚/s
  - Eye-tracked, calibrated each session
  - Perturbation frequency: 1.5-3Hz
  - Full 40˚ FOV preserved, with eccentricity based transparency
    - 0-15˚ eccentricity: fully opaque (α = 1.0)
    - 15-30˚: linear ramp from α = 1.0 -> 0.15
    - 30-40˚: α = 0.15





Discussion

- **Discussion**
  - **AR can make people sick in short periods of time.** Symptoms scale with both rotation speed and perturbation frequency.
  - **Peripheral motion appears to drive the conflict.** Attenuating peripheral content visibility reduced sickness while preserving the central task region, consistent with vection literature. Whether this generalizes beyond our stimulus and task should be tested.
- **Limitations**
  - Small sample (N = 8)
  - Single headset/FOV (Magic Leap 2)
  - Single eccentricity profile tested

References

[1] C. L. Hughes, C. Fidopiastis, K. M. Stanney, P. S. Bailey, and E. Ruiz. The psychometrics of cybersickness in augmented reality. *Frontiers in Virtual Reality*, 1:602954, 2020.
[2] R. S. Kennedy, N. E. Lane, S. Kevin, and M. G. Lilienthal. The simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology*, 3(3):203–220, 1993. doi: 10.1207/s15327108ijap0303
[3] B. Keshavarz and H. Hecht. Validating an efficient method to quantify motion sickness. *Human Factors*, 53(4):415–426, 2011. doi: 10.1177/0018720811403736
[4] S.-C. Freytag, R. Zechner, and M. Kamps. A systematic performance comparison of two smooth pursuit detection algorithms in virtual reality depending on target number, distance, and movement patterns. *Journal of Eye Movement Research*, 15(3):10–16910, 2023.
[5] S. Palmisano and B. Gillam. Stimulus Eccentricity and Spatial Frequency Interact to Determine Circular Vection. *Perception*, 27(9):1067–1077, Sept. 1998. doi: 10.1068/p271067
[6] A.S. Fernandes and S.K. Feiner. Combating VR sickness through subtle dynamic field-of-view modification. Proceedings of the 2016 IEEE Symposium on 3D User Interfaces (3DUI), March 2016. doi:10.1109/3DUI.2016.7460053

Contact

Henry Kam
New York University
henrykam@nyu.edu
gulpinhenry.github.io