

A BOLD approach to mitigating cybersickness: anterior insula rt-fMRI-NF to promote resistance to cybersickness

Nicole Sneddon¹, Stephen Brewster², Frank Pollick¹

¹School of Psychology and Neuroscience, University of Glasgow, Glasgow, Scotland

²School of Computing Science, University of Glasgow, Glasgow, Scotland

Cybersickness, characterised by nausea, oculomotor disturbances and disorientation associated with virtual reality (VR) use, affects approximately 70% of VR users. Neuroimaging studies have consistently implicated the anterior insula in cybersickness, visually induced motion sickness (VIMS) and nausea (Toschi et al., 2017), suggesting a role for disrupted interoceptive processing. Behavioural studies have further indicated that interoceptive processing and affective states contribute to cybersickness, with factors such as state anxiety, stress and altered interoceptive awareness associated with increased susceptibility (Joo et al., 2024; Li et al., 2022; Pot-Kolder et al., 2018).

Real-time fMRI neurofeedback (rt-fMRI-NF) targeting the anterior insula has previously enhanced interoceptive accuracy and increased connectivity with cognitive control, interoceptive and salience networks (Zhang et al., 2023). Given the role of dysregulated interoceptive processing and altered anterior insula activity in cybersickness, it could be suggested that neurofeedback serves as a viable therapeutic avenue. In line with this, an EEG-based brain-computer interface (BCI) has been adopted to alleviate carsickness and seasickness (Bao et al., 2025), however, these interventions may not directly engage the deeper neural systems associated with higher-order interoceptive processing.

The present study will investigate whether rt-fMRI-NF targeting the right anterior insula using a focus-on-heart regulation strategy can improve interoceptive accuracy and increase resistance to cybersickness. Using a double-blind sham-controlled design (Zhang et al., 2023), participants will undergo neurofeedback training to up-regulate anterior insula activity, followed by assessments of interoceptive accuracy and cybersickness susceptibility. We hypothesise that participants receiving real neurofeedback will demonstrate greater right anterior insula activation during training and transfer runs, alongside greater improvements in interoceptive accuracy and cybersickness endurance compared with sham participants.

Methods:

This study will be a randomised double-blind sham (N = 26) vs experimental (N = 26) neurofeedback study. The sham group will receive the experimental feedback trajectory from a matched experimental participant, and the experimental group will receive feedback from the anterior insula (real neurofeedback). Participants will attend a pre-scanning mock trial of a 1st person tunnel simulation (Li et al., 2022) to confirm moderate susceptibility to cybersickness. They will complete a heartbeat counting task (HCT) before and after the virtual reality tunnel simulation. The virtual reality tunnel simulation will last until participants reach a Fast Motion Sickness Scale (FMS) level of 11 or until 20 minutes have passed. If participants complete 20 minutes without reaching an FMS level of 11, they will be deemed resistant to cybersickness and withdrawn from the study. On the second visit, participants will receive neurofeedback. Prior to scanning, a baseline HCT will take place outside of the scanner. Here, participants will count how many heartbeats they count in a fixed time periods (25s, 35s, 40s, 45s) whilst their heartbeat is objectively recorded by a Polar Heart Rate monitor. Participants will then begin scanning. They will complete 5x 30s regulation blocks alternated with 5 x 30s rest blocks. Respectively, participants will be asked

to up-regulate by focusing on their heartbeat whilst remaining completely calm during regulation blocks or to relax during rest blocks. Up-regulation success will be indicated via a thermometer bar that is intermittently presented at the end of each regulate block. A fixation cross will be presented at the beginning for 6s and after each block, participants will be asked to either rate the degree of feeling their heartbeat or the degree of feeling relaxed on a 9-point Likert scale. This Likert scale will be presented for 4s. Participants will complete 4 runs of this paradigm and then a transfer run to see if anterior insula regulation can be achieved in the absence of neurofeedback. After scanning, participants will complete the second HCT and the cybersickness simulation outside of the scanner. Participants will complete the SSQ before and after cybersickness induction. Finally, participants will be debriefed on the two group conditions – sham and experimental – and asked if they know which group assignment was given to them.

Anticipated Outcomes

If hypotheses are supported, this study will provide evidence that anterior insula-targeted rt-fMRI neurofeedback can enhance resistance to cybersickness and modulate interoceptive processing. These findings would advance the mechanistic understanding of the neural processes underlying cybersickness and support the development of targeted neurofeedback interventions. Subsequently, these findings may further clarify the pivotal role of the anterior insula in interoception, demonstrating anterior insula rt-fMRI-NF as a viable intervention to modulate interoceptive abilities. Such approaches may improve the applicability of VR technology in entertainment, education and healthcare domains.

References:

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