Pleasant Locomotion – Towards Reducing Cybersickness using fNIRS during Walking Events in VR

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ABSTRACT
Moving in virtual reality without causing cybersickness is still an unsolved and difficult problem, especially if the virtual space is much larger than the real space and the virtual reality environment asks for quick movements. Many methods to reduce cybersickness are proposed but most of them also reduce immersion. In this paper, we explore the use of fNIRS as an additional modality to detect the level of cybersickness for movement events in VR. We try to mitigate the sickness an individual feels by narrowing the field of vision based on the sickness level detected via measuring increased deoxygenated hemoglobin (Hb) with fNIRS. Our overall goal is to reduce cybersickness in virtual reality applications using physiological signals and appropriate adjustments with little to no impact on immersion.

Author Keywords
fNIRS; virtual reality; VR locomotion; simulator sickness; cybersickness

CCS Concepts
•**Human-centered computing** → **Interaction design;** *Empirical studies in interaction design ;* Systems and tools for interaction design;

Figure 1. Experimental Setup: Participant wearing the VIVE VR headset and an fNIRS (the HOT-1000 from Hitachi connected to the computer over Bluetooth).

INTRODUCTION
VR locomotion has to provide a sensation of moving in VR space that has a different structure than the physical space [18, 17, 15, 16, 21]. Comfortable VR locomotion requires a solution to "cybersickness" [2]. Cybersickness consists of symptoms similar to motion sickness that may happen when a user moves in a virtual reality environment (VRE). These symptoms are also described as simulator sickness. The difference of definition between simulator sickness and cybersickness is that simulator sickness is a subset of motion sickness experienced from travel through VRE. By contrast, cybersickness is the more general term [13]. There are many methods to reduce cybersickness. One of the most used methods is teleportation: A user can move instantly by changing the position of the virtual camera [1]. Narrowing the field of view (FOV) has the potential to reduce cybersickness [7]. Most of the methods that reduce cybersickness are trade-offs between cybersickness and reduced immersion. Therefore, the FOV should only be narrowed when a user's cybersickness is detected but no other suitable methods of reducing sickness for this user have been found. We developed a system that detects a user's cybersickness in real-time by using functional near-infrared spectroscopy (fNIRS) and it can narrow their FOV to reduce cybersickness at the appropriate time for each user. We had two sessions during which we measured the degree of cybersickness, one with our system and one with no narrowing of the FOV. To objectively evaluate cybersickness, we measured cerebral blood flow and heart rate. In addition, the simulator sickness questionnaire (SSQ) was conducted to subjectively evaluate that. Based on these results, we propose an optimal VR locomotion system for each user. Our contributions are as follows: (1) We introduce fNIRS as a novel approach for analysing cybersickness. (2) We propose an adaptive system for handeling varying degrees of tolerance to cybersickness on an individual user level based on fNIRS data. (3) In an initial test, we observed an increase in hemoglobin related to a stress event of locomotion for a participant who experienced cybersickness.

UIST '20 Adjunct, October 20–23, 2020, Virtual Event, USA

ACM ISBN 978-1-4503-7515-3/20/10.
https://doi.org/10.1145/3379350.3416184

RELATED WORK AND APPROACH

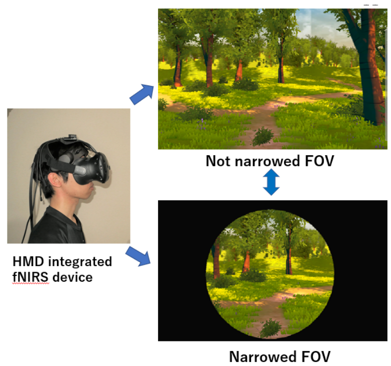

Figure 2. HMD with integrated fNIRS device with proposed interaction.

Cybersickness seems to have high individual variation [19]. There is a lot of work to quantify, detect and mitigate cybersickness, often also called virtual reality sickness[4, 6, 11, 20]. Our approach follows research using physiological signals to estimate the degree of cybersickness in real-time while the user experiences it. We try to apply mitigating methods to limit the sickness for the individual user. In this work, we add fNIRS as a potential detection technology for cybersickness. To the best of our knowledge, we are unaware of any work using a commercial fNIRS for adaptive cybersickness detection and mitigation. So far only medical equipment has been used [8]. There is also work that shows it is easy to integrate fNIRS with headsets [10].

The most common way to assess cybersickness is the use of the Simulator Sickness Questionnaire (SSQ). The SSQ assesses the symptoms caused by simulator sickness, such as nausea, headache and vertigo. The SSQ comes with major advantages/disadvantages of any questionnaire metric. The user might forget the actual scale and it might impact immersion if administered during a VR experience.

There is a lot of research that assesses cybersickness using physiological signals. So far, there is no robust detection mechanism for it [5]. Bruck et al.'s study suggests that increased arousal leads to changes in respiratory rate and low carbon dioxide levels [3]. Kim et al.'s study suggests that the total severity of cybersickness had a significant positive correlation with eye blink rate, heart period, and electroencephalogram (EEG) delta wave etc. [9]. Nakagawa et al.'s study reported that when participants feel low sickness, their respiratory variability and tidal volume are decreased [14]. In this research, we used fNIRS to measure changes in cerebral blood flow and heart rate. Increased cerebral blood flow and heart rate have been related to cybersickness. The major advantages of fNIRS are that it is non invasive and less susceptible to data corruption by movement artifacts compared to EEG[12].

The use of fNIRS to diagnose and mitigate cybersickness could make it possible to provide an individualized solution without interfering with the subject's sense of immersion.

EXPERIMENTAL INSIGHTS

For an initial data exploration we tested our setup with one participant. The subject uses an HMD with an integrated fNIRS device (model Hot 1000 provided by Neu, Figure 1). First, we measured cerebral blood flow change for 5 minutes while the subject was stationary and 5 minutes during a locomotion event (using a controller to move). Based on this we can see an increase in deoxygenated hemoglobin (Hb) for the movement part (blue line in Figure 3) for the movement (locomotion event). The SSQ administered after the recording showed a score of 48 points indicating cybersickness.

In a second test, we set an experimental threshold based on the initial recording of double increase in deoxygenated hemoglobin (Hb) to introduce a narrowed FOV to mitigate cybersickness. The Hb change is shown in the orange line (Figure 3). Apart from that, the setup is the same. When introducing the narrowed FOV based on the hemoglobin change the SSQ score after the locomotion event was 30, moving from the perceivable to the unnoticeable part of the SSQ score for cybersickness.

As shown in previous works, heart rate (recorded also over the fNIRS sensors) is elevated for the case of cybersickness [9], as shown in Figure 4.

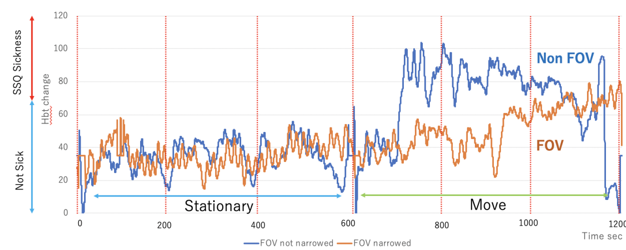

Figure 3. Initial data recordings: deoxygenated hemoglobin (Hb) for a movement event where cybersickness occurred (blue) and where it was mitigated by a narrowed FOV (orange).

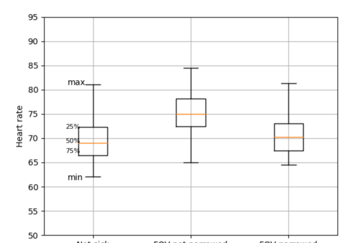

Figure 4. Heart rate for stationary (not sick), FOV not narrowed (sickness occurred) and FOV narrowed (no sickness while moving).

CONCLUSION

We are working on using fNIRS as a novel technology to assess and mitigate cybersickness. It is affordable and can be easily integrated in any VR headset (2 LEDs plus sensors), it provides several physiological signals that are related to cybersickness and our initial data recording seems promising. Based on these insights we plan an experimental setup to evaluate the use of fNIRS in relation to cybersickness events and how to prevent them.

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