Mitigate and Predict Cybersickness Susceptibility - A Systematic and Transparent Evaluation of Working Mechanisms

by

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Synopsis

Virtual reality (VR) is more than stereoscopic images as it allows for the experience of (tele-) presence through immersive features such as interaction with a virtual environment. VR is advantageous for research as a hybrid between laboratory and field studies. For example, the visual input can be fully standardized but there is limitless freedom in how an environment can be represented. Furthermore, physiological and behavioral data are readily available through head-based rendering and controller input tracking without any additional equipment. Moreover, a new level of reproducibility and transparency is achievable when the methods are rigorously described and source codes are shared.

Despite all of these benefits, VR has limitations for accessibility, user experience, and occupational safety due to cybersickness: an unpleasant side effect induced through VR due to a mismatch between various forms of afference, including visual and vestibular, that are involved in spatial self-calibration. Symptoms range from mild forms of general discomfort to headache, vertigo, and emesis. As this phenomenon resembles motion sickness, various non-validated generalizations of motion sickness theories and research exist in the cybersickness literature. This deduction could be oversimplified as working mechanisms differ between the "motion (induced-)sicknesses", which include real (i.e., physical) motion, and those that are visually induced, such as cybersickness. Furthermore, cybersickness research is often not stressing interaction with the VR environment but rather controllability of the visually displayed scene to reduce noise in the experimental data which is common practice for laboratory research. This procedure hinders the comparability of the research findings to real-world use case scenarios that allow for more than passive observation. Therefore, the overarching aim of this dissertation is to systematically validate working mechanisms known from motion sickness research in the context of an interactive and gamified reference VR condition, applied in all studies; apart from small adjustments, the rationale, paradigm, and setup were kept the same, ensuring intersectional comparability of the results. The working mechanisms addressed in this dissertation are systemized by attributing them either to the design of the VR environment, or the individual (physiological reaction or cognitive strategy), or the interaction of the individual with the VR environment.

The first working mechanism addresses the design of the VR environment, as spatial self-calibration is hypothesized to be facilitated using additional virtual reference frames. The participants (N = 110) were matched into treatment (with an additional reference) and control (with no reference) groups according to gender and previous VR experience, two potentially moderating factors. In contrast

to the hypothesis and previous findings, the results showed no treatment effect. This result was not only apparent in the cybersickness questionnaire data but also in the physiological data. In addition, no significant difference in gender-specific effects was found. However, the results show that previous VR experience reduced the likelihood of experiencing cybersickness, and descriptively more males reported previous VR experience. These results could explain the ambiguous effect of gender on cybersickness susceptibility, as it might be mediated by previous VR experience.

Moreover, on an individual level, VR-induced physiological reactions to visual motion (i.e., eye movement patterns) might serve diagnostic purposes. Therefore, participants (N = 59) were exposed to a virtual optokinetic drum, and their eye movement patterns during and after the drum exposition were analyzed to predict their susceptibility to cybersickness in the reference VR. However, the results were ambiguous, due to marginal data quality, conservative preprocessing, and more frequent blink events with prolonged VR exposure, suggesting behavioral adaptation to the stressful stimuli.

In addition to the individual's physiological reaction, cognitive abilities could differentiate between them. One of these abilities focuses on the individual's handling of conflicting information (e.g., mismatching visual and vestibular afferences) for spatial calibration. In case individuals show a higher awareness of the conflicting information, they should experience a stronger mismatch, and therefore more cybersickness. The awareness of conflicting information is measurable through performance measures in a cognitive test, that 76 participants underwent for this dissertation. Interestingly, the postulated correlational effect was not universally confirmed but rather found for those participants who had been previously exposed to the cybersickness-inducing reference VR. These results additionally argue in favor of adaptational strategies including sensory reweighting of conflicting information.

At the intersection of the factors mentioned above, the individual's interaction with the environment has a direct effect on the visual flow as it is coupled with the individual's head movement and controller input in a bidirectional way. These interactions with the environment were used to model the mean expected symptom severity of the upcoming cybersickness rating. The head movements and controller input of 169 participants were available for the analysis. The postulated head-movement-based cybersickness dose value allowed for a global prediction of 5.4% of the total variability of cybersickness depending on time spent in VR and might be a suitable theoretical complement to data-driven machine learning algorithms.

To return to the starting point once more, the design of all VR environments was addressed in a synoptical comparison of all studies. A Confirmatory Factor Analysis (N = 245) for a cybersickness symptom questionnaire with the moderating factor of VR environment stressed the environment-specificity of symptom reports. Although a moderate agreement with the overall model was achieved, the fit indicators revealed misspecifications for two-thirds of the environments. This finding underlines the argument that ecologically valid VR setups are needed to investigate cybersickness and that open science methods are not only academic apprentice pieces but required for adequate categorization of research data.

In conclusion, a holistic consideration of all three factors is important to classify research results; for an integrative comparison between cybersickness studies, clear definitions, and transparent research methods are required. This dissertation addresses this claim by sharing the research data and describing them extensively, as well as sharing the source code of the VR applications and providing a good practice example for the application of open-source eye tracking methods. The evidence suggests that findings from motion sickness research should not be applied to cybersickness without detailed validation for several reasons: One reason is some technical limitations of the deployed equipment, the next reason is the environment-specific effects and the interaction with the VR environment itself which limit the generalizability, and the last reason is the mediation of cybersickness not only through descriptively self-reported but also through experimentally manipulated individual's previous experience. Hence, the application of open science not only ensures replications and serves good scientific practice but also enables a holistic approach to a systematic evaluation of theories in the context of cybersickness. Since a major challenge is reducible to an unclear definition of VR and cybersickness, it should further be thought "outside the disciplines" to let different approaches complement each other for a facilitated classification of the current and future results.