Factors of Cybersickness

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Abstract. As virtual reality (VR) applications expand in private and public sector contexts, so do reports of sickness elicited within VR systems. Users of head mounted VR displays frequently report symptoms similar, but not identical, to those of motion sickness and simulator sickness. Because of this distinction, the symptoms are collectively classified as symptoms of cybersickness. While researchers and tech developers alike acknowledge VR's propensity for inducing cybersickness, there is no symptom prediction tool. The present paper describes a research agenda which will culminate in a cybsersickness prediction tool. First, the authors clarify nomenclature relevant to the VR, virtual environments (VE), and cybersickness. The preliminary literature review resulted in a test Cybersickness Index Matrix (CIM), with three cybersickness trigger categories: System, Task, Individual Differences. Researchers conducted a validation test of the CIM in a pilot study conducted in conjunction with an energy industry training program. The paper presents those preliminary results and provides a discussion including CIM refinement and future implementation potential.

Keywords: Cybersickness · Virtual reality · Human factors

1 Clarifying Cybersickness

1.1 Common Language for Common Ground

In November of 2015, a The Telegraph Health News headline read, "Cybersickness: The new 'illness' sweeping the nation" [1]. Briefly, the article proposed a pandemic of nausea, headache and some blanket of malaise triggered by the things people viewed—especially their electronic devices, like cell phones. While the sensational headline likely hooks the interest of a reader, it fails to capture the phenomenon that virtual reality(VR) developers and human factors researchers are seeking to understand when considering cybersickness (CS). It is neither "new" nor "sweeping" the UK or any other nation.

CS is not new, especially if it is defined as a physiological illness like motion sickness (MS) triggered by atypical visual stimuli. For decades, researchers have examined visually induced MS, considering the relationship between the optical, vestibular, and proprioceptive systems. Aeronautic research had established a compelling relationship between MS and spatial perception [2]. US investment in space exploration compelled NASA scientists to consider the physiological catalysts of MS

C. Stephanidis (Ed.): HCII Posters 2017, Part II, CCIS 714, pp. 3–8, 2017.
DOI: 10.1007/978-3-319-58753-0_1

from a variety of sources, including optical perception. While obvious sources like zero gravity and high-rate rotations could make a body respond to genuine motion-induced sickness, researchers also observed that visual exposure to angular accelerations altered the experience of MS [3].

Further, it would be difficult to argue that it is spreading rampantly. Rather, people are placing themselves in situations that are more apt to trigger visually induced MS through frequent use of digital displays. There is simply no evolutionary precedent for the regular consumption of light-emitting visual stimulation as many humans currently experience.

But, something *is* going on. VR headsets come with warnings about experiencing symptoms of MS during use. National Science Foundation and other scientific sources fund CS research. Newspapers are running articles warning people of the cybersickness epidemic. Yet, as long as we cannot define the phenomenon, we cannot move toward a solution. The present work aims to contribute to a clearer working definition of CS and offer a framework for analyzing and predicting CS risk.

In order to examine what cybersickness is and determine how best to address it, we must settle on a definition. Does it include any digital display (like a desktop or cell phone), is it limited to virtual reality, or is further limited to head-mounted display? Is it to be considered as a product of vection displacement or perception of any motion? Is it only cyber if the body isn't moving? Is it distinct from motion sickness and simulator sickness?

While we will propose answers to each of those questions so that we may work toward addressing the problem, we start with the final question, as it requires a conceptual clarification between three tightly related constructs: CS, motion sickness, and simulator sickness (SS).

Although the researchers who first shaped the notion of have mapped a cogent distinction between CS and SS, research on CS continues to be conducted using the metrics of SS. They argue that the profile of CS symptoms emphasizes disorientation, diminishes oculomotor discomfort relative to SS, and presents with three times the severity of symptoms over SS [4]. The authors assert that CS and SS are types of motion sickness, but distinct from one another. Nonetheless, numerous studies examining CS use the simulator sickness questionnaire (SSQ) as the metric [5–7].

This brings the discussion to a point that requires clarification of CS symptoms and the conditions under which CS occurs. To this end, we offer four points to clarify our use of the term "cybersickness":

1. CS symptoms include: Disorientation, dizziness, eyestrain, headache, sweating, fatigue, stomach discomfort, nausea/stomach discomfort, vertigo, blurred vision.
2. CS symptoms emerge from exposure to cyber sources.
3. Although CS shares symptoms with motion sickness, it is not a type of motion sickness.
4. Individual differences, task features, and cyber/technical system features contribute to risk of experiencing CS symptoms.

Just as a cold is not the flu, the symptoms of CS may resemble motion sickness, but because the root causes are distinct, the present work requires a distinction. For the purpose of our research, motion sickness, as the name implies, is triggered by *motion* and it involves the vestibular system with or without a visual stimulus. While Stanney et al. [4] propose CS as distinct from SS and both as types of motion sickness; we assert that it is more helpful to categorize SS as one subset or type of CS when triggered by cyber display. This means that simulators that are not cyber-based (such as the original Link Trainer) may elicit SS, but without a cyber display would not be eliciting CS. Likewise, motion-based simulators elicit may elicit a type of motion sickness.

These distinctions matter, as they help to establish the categories by which we can begin to not only understand, but also predict the incidents of CS. The following sections moves beyond the cyber/motion distinction sketched above to examine the contributions from individual differences and the technical cyber system. These contributions then form the theoretical justification for the Cybersickness Index Matrix (CIM).

2 Contributors to CS

In the preceding section, we mapped our rationale for isolating the CS discussion to include VR, virtual environments, and other potential CS-inducing cases to the ones that are distinctly *cyber*, and not necessarily motion-based or simulation-based. Now, we provide examples of the other factors and features that may contribute to CS. These factors come from three key sources: the context, the individual, and the technical system.

2.1 Contextual Contributions

Context contributors to CS risk include contextual constraints such as:

- Environmental conditions: temperature, humidity, ambient noise
- Performance requirements: physiological, psycho-cognitive, affective (as determined by appropriate measures of effort, duration, complexity, and resonance)
- Human-in-system factors: habituation, exposure duration

While the environmental contributions may be evident (for example, one will likely see an increase in the symptom of sweat and fatigue in hot, balmy conditions), the other contextual contributors are equally important. For performance requirements, the physiological stress symptoms rise during physically, mentally, or emotionally difficult tasks. However, other aspects of the performance, such as whether one must move one's head, could inadvertently increase risk [8]. Other studies suggest that habituation may reduce CS symptoms.

2.2 Individual Differences

Individual differences contributing to the risk of CS include:

- Bodily traits: binocular disruption, body mass index (BMI), general health, migraine propensity

- Behavioral conditions: time since eating, sleep patterns
- Symptomatic propensity: motion sickness history, prior negative experiences
- Psychological traits: Risk taking, openness, motivation

As one may expect, the individual differences research in CS runs a gamut from fairly well-established factors to more highly disputed. Stanney and associates studied susceptibility to these symptoms in a virtual environment finding a significant correlation with self-reported history of motion sickness [9].

In respect to individual differences, we face a challenge to find a balance between reducing risk from some individual sources For example, the connection between BMI and oculomotor symptoms in a virtual environment are clear [9]. However, a high BMI may be related to the reason one should be in a virtual environment. Case in point would be a study from Riva et al. [10], where the researchers were using VR technology as body-image therapeutic treatment. Participants demonstrated positive benefits from the therapy, but they also demonstrated high symptoms as measured on the SSQ. A higher BMI clearly would not justify exclusion from such a treatment, but researchers should consider it as a factor (as it was in that study) so treatments could be employed in the safest fashion.

2.3 Technical System

Some variance in CS symptom risk is due to aspects of the cyber system, such as:

- Hardware: type of display (e.g. head mount, projection, desktop), comfort of design,
- Visual experience: 2D vs 3D, scene oscillation, navigation speed, navigation control, vection
- Hardware/software interaction: delay, locus of control

In this category, research has demonstrated that hardware and software features trigger CS. For example, display type influences CS, with head mounted displays contributing the most risk [11, 12]. Further, researchers are confident that dimensionality and vection influence CS [13, 14]. The interactions between the hardware and software can also introduce CS risk, as studies involving the locus of control [12, 15] suggest.

3 Known Unknowns

While our comprehensive literature review suggests that the three categories of contribution are adequate for framing CS, the lack of research employing this framework at high granularity suggests that there are more sub-factors that remain to be studied. For example, psychological traits have been correlated with MS and SS [16], but how do they relate to CS, specifically? Further how do these factors relate to one another?

Further, because these constructs (MS, CS, and SS) have been collapsed in much of the research, it is unclear whether the affects observed are applicable when the stimulus changes by display, task, and so forth. Take the role of gender, clearly an individual difference, but the impact of gender on CS remains disputable. Some research suggests that female gender increases susceptibility to CS [9, 17, 18], where another study suggests males are more succeptible to MS [19] whereas other studies suggest that there is no significant risk associated with gender [17]. Gender is not the only contributing factor in dispute. Similar conflicting research results abound for age and ethnicity. We propose that future studies should be clearer about what construct is under investigation (CS/MS/SS), what tools are being used to measure the construct, and clarify any mitigating/moderating variables within the study.

4 Toward CS Prediction

Appreciation of the complex interactions among and between contributing factors can lead to the development of a predictive model. The authors of this paper are currently working on the Cybersickness Index Matrix (CIM) to provide guidance for cyber users. By taking those relationships into account prior to cyber exposure, users can reduce risk in entertainment, training, and work contexts. The final goal is to establish an open-source tool using fuzzy metrics to give users a "quick and dirty" evaluation of risk given a unique set of circumstances from context, individuals, and systems. A verification and validation study is under way testing the model on an international sample of trainees using virtual reality training for the energy industry.

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