Assessing Discomfort in Mixed Reality using Subjective Measures

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The assessment of discomfort is an important part and ongoing challenge of user experience evaluation in mixed reality (MR) systems. Problems, such as the definition of appropriate rating scales, repeated exposure of participants to the systems, or assessing relative symptom scores by repeatedly employing questionnaires, in particular, complicate the subjective assessment. Furthermore, the large number of existing terms and concepts of discomfort and symptoms makes it difficult to compare studies. Finally, the rapid changes in technology heavily influence the experience and assessment of discomfort, and therefore, measures have to be constantly reevaluated. This position paper aims to raise awareness of the ongoing challenge of assessing discomfort in MR. Grounded in our prior work, we discuss five specific problems that we identified as critical factors of the subjective assessment of discomfort in MR systems.

CCS Concepts: • **Human-centered computing → Mixed / augmented reality**; • **Applied computing → Consumer health**.

Additional Key Words and Phrases: discomfort, mixed reality, self-assessment, simulator sickness, digital eye strain

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1 INTRODUCTION

When using augmented or virtual reality (AR/VR) technology, negative side effects, such as feeling nauseous or uncomfortable, frequently occur [25]. These signals of discomfort with MR systems are referred to with several terms, including simulator sickness [11], cybersickness [20], and VR sickness [9]. In addition to these well-known concepts in the field of MR research, there are other problems associated with exposure to AR and VR technology that can negatively influence the user experience, such as digital eye strain or ergonomic issues [6].

In the following, we define the term *discomfort* as the occurrence of negative physiological effects that arise during usage of an AR or VR head-mounted display (HMD) in an undesirable manner that affects users in their well-being, health, and user experience. With MR technology – currently predominantly VR HMDs – being increasingly adopted by consumers, one can expect symptoms of discomfort to become even more prevalent in the future, as users are already experiencing these negative aspects during usage [25].

Beginning with research on sickness symptoms in simulators over 30 years ago [10], discomfort has become a constant interest in the MR research community [3, 21]. Yet, several uncertainties remain on this topic, such as differentiating concepts that contribute to discomfort in MR (e.g., simulator sickness, cybersickness, visual discomfort [6]), a clear list of causes [3], or the relationship of discomfort and other MR user experience metrics, such as immersion.

While physiological measures have been proposed for assessing discomfort (e.g., electroencephalography or eye tracking to assess objective eye strain [19, 24]), the vast majority of measurements used are subjective self-report measures [6]. One cause for this might be that physiological measures often require expert knowledge or external equipment, such as high-accuracy eye trackers [24]. To assess discomfort subjectively, several questionnaires have been proposed (e.g., Simulator Sickness Questionnaire (SSQ) [12], Revised SSQ [14], Virtual Reality Sickness Questionnaire (VRSQ), [15] or Cybersickness Questionnaire (CSQ) [23]). In addition to the issues that apply to questionnaires in MR research in general (e.g., whether questionnaires should be embedded directly in the experience or be employed on

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an external device as described in the workshop proposal [1]), specific challenges further complicate the assessment of discomfort. For instance, to avoid carry-over effects of symptoms, studies are usually conducted over an extended period of time period or require repeated participation of study participants.

Lastly, it is currently unknown how discomfort relates to other MR user experience concepts, such as presence and immersion. As the feeling of being immersed in a virtual world increases, awareness and attention to the real world decreases [22]. This might lead to interesting interaction effects of the perception of discomfort and presence. In fact, studies showed that presence and simulator sickness are negatively correlated [8, 18]. However, to the best of our knowledge, such a relation for general discomfort and presence is currently unknown.

With this position paper, we argue that the assessment of discomfort is an essential part of evaluating user experience in MR. Grounded in our prior work, we present five critical challenges in assessing discomfort in MR. Finally, we discuss the topic from a more general perspective and aim to trigger a discussion during the workshop about how discomfort and other user experience measures in MR relate.

2 CHALLENGES IN SUBJECTIVE ASSESSMENT OF DISCOMFORT IN MIXED REALITY

2.1 Challenges in Employing Discomfort Questionnaires

The best administration practice of discomfort questionnaires, i.e., employing a questionnaire only once after the experiment to measure absolute values or employing it before and after the experiment to measure relative discomfort values, remains an open question. Furthermore, to register more fine-granular changes in relative symptom scores, questionnaires must be employed repeatedly during the experiment. However, researchers found that the repeated employment of questionnaires can influence participants' rating of concepts [26]. The authors of the SSQ considered this problem by defining that the questionnaire should only be applied to healthy participants who do not experience any symptoms of discomfort before the experiment [12]. However, there is no common consensus in the community whether discomfort questionnaires should be employed post-experiment only or pre- and post-experiment [6].

Ethical Considerations. Depending on the study's goal, the extent to which participants may be exposed to negative side effects of the technology must be carefully evaluated. In particular, investigating a potential alleviation method for discomfort in MR, requires participants to first experience symptoms. This can be achieved either by prolonged exposure to the device or by intentionally designing experiences in a negative manner to introduce symptoms. This intentional exposure of study participants to negative effects, needs to be discussed and ethically evaluated by the community.

Questionnaire Scope. A third challenge is the scope or length of questionnaires. Questionnaires that cover a wide range of symptoms require study participants to answer a relatively large number of questions. This may take time and prolong the experiment and is especially difficult when a measure is applied to depict a fine-granular course of symptoms (i.e., several measurements during the experiment). On the other hand, it is difficult to break down a complex set of discomfort symptoms into single-item questions that can be applied without further detail. A potential compromise might be to use the complete questionnaire before and after the experiment and to reduce the measurement during the experiment to a single question (similar to single-item questions about simulator sickness [5, 13]).

Rating Scale. The employment of suitable rating scales presents the fourth challenge. In the medical domain, symptoms assessed with self-report measures are usually recorded with symptom severity or pain scales [7]. In the field of human-computer interaction, "Borg's perceived exertion and pain scales" [2] have often been applied to assess

discomfort/comfort of wearable devices (e.g., to assess the comfort of wearable devices [16], including HMDs [17]). Common discomfort questionnaires that are applied in MR systems are often based on symptom severity scales, reaching from "no experience of symptoms" to "very severe experience of symptoms" (e.g., SSQ [12]). However, because researchers in the field of MR are assessing symptoms that occur with consumer devices, it is questionable whether a scale that, at its extreme, would indicate that participants are experiencing very severe symptoms is appropriate for assessing symptoms. This suggests that changes in symptom severity are often less severe than could be measured by these scales. A potential solution to this problem could be to provide a more fine-granular scale that indicates issues before they become very severe.

Repeated Exposure. One specific challenge of measuring discomfort in general, is the repeated exposure to the technology, as usually a "discomfort condition" needs to be compared to a baseline condition. This leads to the need for repeated-measures studies that examine and assess discomfort in MR settings to be conducted on different days or with a considerable number of breaks between conditions to avoid carry-over effects of symptoms (e.g., as employed by Draper et al. [4]). This has practical implications on the study duration, as it means that studies are either of long duration, allowing participants to recover between conditions, or that studies have to be conducted over the course of several days.

2.2 General Challenges in the Assessment of Discomfort in Mixed Reality

Besides the issues that specifically refer to the employment of subjective discomfort measures, there are additional general challenges that influence the measurement of discomfort in MR. For instance, due to the rapid changes in technology, the evaluation of discomfort must be constantly reevaluated. The past has shown that questionnaires developed for a different type of technology might not be entirely suitable to assess symptoms of current devices. For example, the SSQ was developed for a new type of simulation technology [12] because the assessment of symptoms with the motion sickness questionnaire was no longer accurate enough. Similarly, recent research suggests that the SSQ, which is commonly used to assess symptoms of discomfort in MR systems now, might need to be reevaluated for its suitability to MR systems because of potential changes in technology and symptomatology [6]. Another general problem is the unclear differentiation of terms. As listed above, a variety of questionnaires exist that seem to measure similar or related constructs. However, the differentiation of the constructs these questionnaires measure is currently unclear. Lastly, the relationship between the concepts of discomfort and MR usability metrics, such as presence and immersion, has not conclusively been defined. An increased feeling of immersion could lead to a reduction in the experience of DES symptoms, as users are increasingly captivated by the virtual world and might consciously or unconsciously suppress negative feelings, including discomfort. For simulator sickness, researchers found a negative correlation with presence and immersion [8, 18]. However, this question remains open for general discomfort.

3 CONCLUSION

This position paper discusses five specific challenges when measuring discomfort in MR technology and highlights that assessing discomfort is an ongoing challenge for MR researchers. Furthermore, it highlights that the impact of discomfort on general concepts of MR user experience, such as presence and immersion, is currently unknown. The workshop on "Evaluating User Experience in Mixed Reality" would be an excellent opportunity to further discuss these issues and find potential solutions to some of the problems.

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