Design and evaluation of a continuous interface for real-time self-reporting of VR sickness

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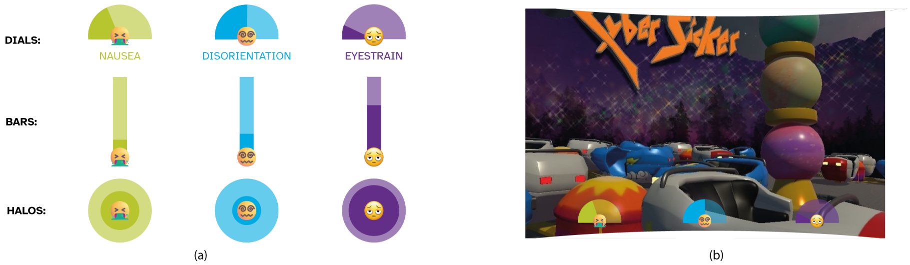

(a) (b)

Fig. 1. (a) Overview of the three interface prototypes designed and evaluated in this study, shown in order of user preference (top-down). Each prototype consists of three elements representing each symptom dimension of VR sickness (nausea, disorientation, and oculomotor), and employs distinct colors selected to be intuitive and easily distinguishable. The labels shown at the bottom correspond to the on-demand wording reference displayed when a button is pressed. (b) The preferred continuous interface implemented in the VR sickness-inducing scene chosen for the study [56].

Precise measurements of sickness symptoms induced during a virtual reality (VR) experience are essential for evaluating VR systems and developing designs oriented toward usability, safety and user acceptance. However, VR sickness assessment typically relies either on discrete self-report questionnaires (which lack temporal resolution, interrupt the experience, thus reducing immersion, and provide coarse snapshots of symptom evolution) or on objective signals obtained with biosensors, which typically require extensive post-processing and interpretation. To address these shortcomings, we propose a continuous interface for real-time self-reporting of VR sickness, designed following a human-centered methodology. We design and evaluate three interface prototypes that allow users to report symptom intensity while remaining fully immersed in the virtual scene. Our findings demonstrate that users significantly prefer the continuous nature of our interfaces over the discrete Likert Scales of traditional questionnaires, identifying them as a more intuitive and less cognitively demanding alternative. In addition, the study allows us to identify the most suitable design according to user-centered criteria. Our contribution is an empirically evaluated continuous interface for real-time VR sickness assessment.

CCS Concepts: • **Human-centered computing** → **Interaction design**; **Interactive systems and tools**.

Additional Key Words and Phrases: Virtual Reality sickness, questionnaire, continuous real-time self-report, interface, CSQ-VR, Human Centered Design

1 Introduction

Virtual Reality (VR) is increasingly used across entertainment, education, training, healthcare, and industry, gradually becoming part of everyday life. However, this growth is confronted with a significant challenge: adverse health effects resulting from immersive systems, often referred to

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as "cybersickness." The phenomenon is described using other terms: motion sickness, simulator sickness, or Virtual Reality Induced Symptoms and Effects (VRISE) [11]. These are related but not identical, differing mainly in their causes. Because our work addresses the broad issue of sickness experienced during VR immersion, without restricting its specific origin, we use the general term *VR sickness* throughout this paper [24].

Although extensive research has explored the origins of VR sickness and developed numerous techniques to mitigate it [5], far fewer innovations have emerged in how it is measured. Existing approaches can be broadly classified into objective and subjective methods [9]. Objective methods have lately expanded due to recent advances in biosensors (e.g., Galvanic Skin Response, heart rate, eye tracking), yet these signals are costly, technically demanding, and difficult to interpret in real time. Conversely, subjective assessments remain dominated by questionnaires and scales. These address the three dimensions of VR sickness into which symptoms are typically clustered: nausea (for symptoms related to stomach awareness, increased salivation, burping), disorientation (for symptoms related to dizziness, vertigo), and oculomotor (for symptoms related to eyestrain, difficulty focusing, blurred vision, headache) [14, 25, 29]. Questionnaires and scales are usually applied before and after the VR experience, thus failing to capture the temporal evolution of the symptoms. Alternatively, they may also be applied halfway through, requiring the users to take out their head-mounted displays (HMD) thereby disrupting immersion. Real-time information of VR sickness could support not only retrospective evaluation of experience designs, but also the development of user-centered adaptive immersive systems in which scenes respond dynamically to the users' current symptoms. This gap highlights the need for immersive self-report tools capable of monitoring symptoms continuously throughout the VR session.

Recent research has proposed embedding questionnaires or scales directly inside the VR environment [29, 36, 40], developing tools that facilitate less intrusive and more frequent data collection [26, 31, 41, 49]. However, these approaches either still rely on discrete measures, or fail to capture all three dimensions of VR sickness and therefore, do not provide a comprehensive method for continuous self-report of VR sickness during immersion.

Continuous self-reporting, on the other hand, offers the possibility of a more intuitive and cognitively less demanding interaction with a graphical interface [47], and has been explored in other areas of Human-Computer Interaction (HCI). Existing methods can be classified into four types: **"Linear models"**, which encode intensity along a single axis, typically using a bar-like representation [4, 13, 16, 19, 49]; **"Circle models"**, where the diameter of a circle or halo reflects the magnitude of the signal [50–53, 55]; **"Rotary models"** which feature rotary or angular indicators reminiscent of kitchen knobs or automotive speedometers, and are often operated via dial style controllers [1, 10, 30]; and **"Quadrant-based models"**, which map data onto a two-dimensional Cartesian plane, typically representing arousal and valence [2, 12, 18, 20, 32, 43–46, 48, 54].

In this work, we investigate the question of how to design a continuous interface for real-time self-reporting of VR sickness, comparable with current validated questionnaires but without disrupting immersion. Inspired by the approaches of other areas in HCI and following a user-centered design methodology [17, 34, 42], we developed three design principles (see Section 2) that served as heuristics to narrow down the design space and guide us to design three different interface prototypes. This allows us to validate the feasibility of continuous VR sickness self-reporting, while also identifying which of the three designs works best according to user-centered evaluation criteria. Our findings show that users significantly prefer the fluid nature of our continuous real-time reporting over discrete alternatives, finding it more intuitive and less cognitively demanding, while also reducing disruption.

2 Design Principles

We take into account three main design principles, which will guide the placement, behavior, and feedback logic of our interface.

P1. Design for a good VR experience. Rebelo et al. [38] defined the *i3 VR* user-experience triangle: immersion, interaction, and imagination. Regarding *immersion*, and since our interface will be used inside the VR environment, it must remain visible without becoming distracting. To support *interaction*, all its elements must offer a comfortable, predictable, and consistent behavior, maintaining a unified logic to reduce cognitive effort and prevent errors. Last, to support *imagination*, the interface should add as little mental workload as possible, so that users can direct their attentional resources and engagement towards the virtual environment itself.

P2. Design for Universal Access and Human-Centered Interaction guidelines. Our interface should follow established Human-Centered Interaction guidelines, for which we turn to Jerald's book on Human-Centered Design for Virtual Reality [24]. It should also follow Norman's foundational usability principles [33]. Together, these guidelines allow us to enable universal access, comfortable even under varying levels of VR sickness. The specific visual, functional, and interaction decisions informed by these principles are detailed in the following sections.

P3. Design for a ground truth. Lastly, the effectiveness of our interface must be comparable to well-established VR sickness questionnaires, without breaking immersion. The Simulator Sickness Questionnaire (SSQ) [25] has been widely used in VR research. However, it was developed as an adaptation of the earlier Motion Sickness Questionnaire (MSQ) [37], and does not entirely match the phenomenology of VR-induced symptoms [39]. In response to these limitations, instead, the shorter Cybersickness in VR Questionnaire (CSQ-VR) (based on 7-point Likert Scale) was explicitly developed and validated within immersive VR contexts [15, 28, 29]. We thus select CSQ-VR as ground-truth questionnaire to evaluate our proposal.

Conclusion. Based on these principles, we narrow down the design space of our interface by focusing on three of the four types identified in the Introduction: Linear, Circle, and Rotary models. We discard the fourth option, Quadrant-based models, since VR sickness does not map meaningfully onto two-axis spaces.

3 Interface Adaptations

We make the following adaptations to the three remaining types of interfaces, to accommodate for the particular case of VR sickness.

Visual design. We design three interfaces, inspired by existing continuous self-reporting techniques: *Bars* (derived from Linear models and implemented as vertical bars), *Halos* (based on the Circle family), and *Dials* (a semicircular gauge implemented as an adaptation of the Rotary model). Each prototype consists of three distinct elements, allowing users to independently report the three symptom dimensions of VR sickness: nausea, disorientation, and oculomotor. These interfaces are shown in Fig. 1(a).

Semantic layer. By default, no textual labels are displayed; instead, we assign a distinct icon to convey each symptom, minimizing visual load and supporting rapid recognition [1, 6, 7, 46, 48, 50]. When needed, users can activate an on-demand wording reference by pressing a button, temporarily showing a brief label describing each of the three symptom dimensions. We use Atkinsons Hyperlegible, a typeface recommended by the Braille Institute for visually impaired users [35].

Visual encoding. We assign a discriminable color to each symptom [22], chosen to remain distinguishable even under color-blindness conditions (HEX values: yellow-green #A2C523 for nausea; soft blue #3FA7D6 for disorientation; violet #6A1B9A for oculomotor). We use low-saturation tones, subtle shadows, and controlled transparency to reduce visual fatigue and support divided attention, allowing the interface to remain perceptible without competing with the virtual scene [21].

Functional design. All interface elements are head locked within the ergonomic field of view, positioned in a lower centered location for constant visibility. Interaction is performed via the HMD controller: users point at a symptom element, select it using the trigger, and adjust the intensity using the joystick (chosen for its return spring mechanisms, which allow users to sense the neutral position without visual confirmation, again reducing cognitive load [2, 39]). Interface feedback includes audiovisual cues: a brief sound plus white highlight when hovering, red highlight during selection via the trigger.

4 Evaluating the design

Prior to the formal study, we conducted several feedback pilot rounds with three HCI researchers. The formal study was reviewed by our institute's regional ethics committee. The within-subjects design involved three sessions on separate days, one for each interface design in random order, to mitigate potential memory issues. Before participation, all individuals reviewed and signed the informed consent form and received instructions about the study's objectives and procedure. The study was divided in three phases: Questionnaires; VR experience; and Feedback. In the first phase, participants completed an online questionnaire collecting demographics, their past experience with immersive environments, as well as the Visually Induced Motion Sickness Susceptibility Questionnaire (VIMSSQ) [27] to assess their predisposition to sickness and their current state. Next, participants sat in a non-rotating chair with armrests, since studies indicate that standing induces more VR sickness compared to a seated posture [3, 57], and received instructions on how to put on and calibrate the Varjo XR-4 HMD and controller. At the beginning of the second phase, participants spent the first five minutes in a training scene, designed to help them familiarize with VR, learn how to interact with the interface, and understand the three VR symptom dimensions and their mapping to the on-demand wording reference (see supplementary material S.1 for a description of the training scene). After that, the actual test begins. Participants were asked to annotate their symptoms using the given interface while immersed in the Cybersicker amusement ride scene (see Fig. 1 (b)), which was selected because it was specifically designed to study induced effects of VR sickness [56]. This lasted ten minutes, since cybersickness symptoms are typically noticed within this timeframe [11, 23]. We modified the motion speed and acceleration of the scene to elicit varying levels of discomfort and capture dynamic symptom fluctuations (see S.2 of the supplementary material for a description of the speed modification in the scene). All scene parameters, together with the user's current symptoms intensities, are continuously logged to enable the subsequent evaluation of the three interfaces designs. To minimize external factors, no music was played during this phase [28]. Participants verbally answered the CSQ-VR at the beginning, middle and at the end of the experience [49], but without removing the HMD or introducing additional on-screen interaction. They could stop the experiment at any time.

Once the experience was over, the HMD and controller were taken off, and participants completed the third phase by answering the System Usability Scale (SUS) [8] for both the interface used and the 7-point Likert Scale CSQ-VR, followed by a brief, semi-structured interview to collect qualitative feedback and identify potential interface improvements. In total, the duration was approximately 45 minutes on day one, and 25 minutes on days two and three, since less training was required. After testing the three interfaces, participants ranked them during the interview.

4.1 Results

We evaluate the proposed interfaces according to three main objectives:

O1. Ground truth agreement: Assessing whether continuous interfaces are comparable to the CSQ-VR questionnaire used as ground truth. **O2. Temporal sensitivity:** Examining if the proposed interfaces capture the continuous evolution of symptoms better than discrete traditional questionnaires. **O3. User experience comparison:** Identifying which of the three designs (Bars, Halos or Dials) achieves better usability, acceptance, and comfort.

A total of 25 participants (average age = 27.12, M = 15, F = 10) took part. Of these, 56% reported frequent prior use of VR, 40% reported limited prior experience (less than 5 uses), and 4% reported no prior VR exposure. One participant had cochlear implants due to hearing impairment, and two participants reported color-blindness. We analyze data collected from the CSQ-VR questionnaire, the continuous interface, and the interviews to evaluate the proposed designs.

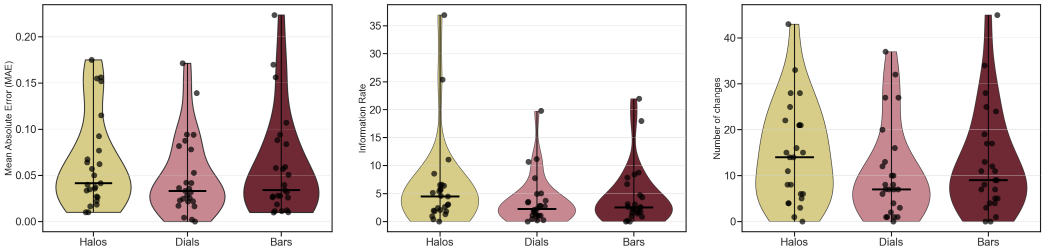

Fig. 2. Distribution of the Mean Absolute Error of the proposed interfaces with respect to the CSQ-VR questionnaire (left), Information Rate (center), and the detected Number of changes (right). Horizontal lines denote the median, and dots correspond to individual participants. All interfaces show comparable performance across metrics, with no statistically significant differences between them. MAE values indicate comparable agreement with the CSQ-VR across interfaces. Both Information Rate and Number of changes are substantially higher for the interactive interfaces than for the CSQ-VR baseline (IR $\approx 10^{-4}$ and at most two changes, as the questionnaire is administered three times), reflecting their ability to capture continuous user input.

O1. Ground truth agreement. To evaluate the accuracy of VR sickness estimates provided by our interfaces, we computed the mean absolute error (MAE) between interface-based measurements and the scores obtained from the standardized CSQ-VR, administered at three discrete time points. Fig. 2 (left) summarizes MAE results across the three interfaces (MAE values range from 0 to 1, with lower values indicating closer agreement with the reference measure). Normality assumptions were mildly violated (Shapiro–Wilk test on within-subject residuals, p = .024); therefore, we report non-parametric analyses. A Friedman test ($\chi^2(2) = 3.44$, p = .18) did not reveal significant differences in MAE across interface conditions. Post-hoc pairwise comparisons confirmed the absence of meaningful differences between interfaces. Overall, all interface conditions yielded low estimation errors, confirming good agreement with the standardized questionnaire.

O2. Temporal sensitivity. To characterize how efficiently participants conveyed information through the proposed interfaces, we computed the Information Rate (IR), which measures the amount of information conveyed per unit time. It is computed as the sum of changes in the reported signal across consecutive samples, normalized by the total elapsed time between samples. Higher IR values indicate more frequent and/or larger user adjustments (more efficient information transmission). In addition to IR, we also quantified the Number of changes in the signal (i.e., adjustments exceeding a threshold) during the task, as a more direct measure of how often participants updated the interface.

Fig. 2 shows IR (center) and the Number of changes (right) across interface conditions. Normality was strongly violated for both IR and Number of changes (Shapiro–Wilk tests on within-subject

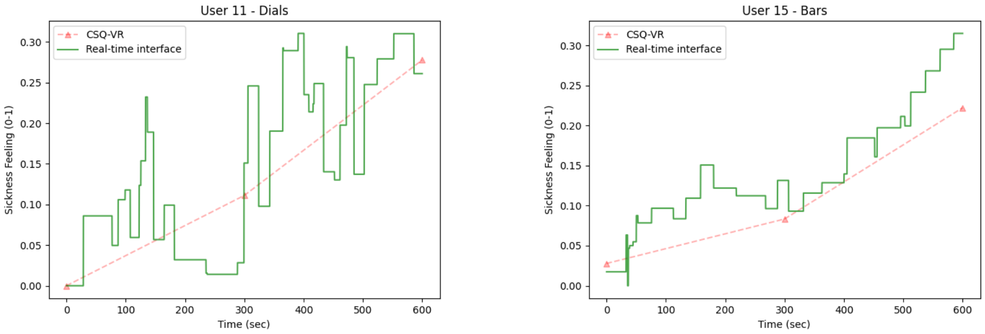

Fig. 3. Two representative examples of individual time-series showing VR sickness intensity over time recorded with the continuous interface (green) and the CSQ-VR questionnaire (red). The VR sickness estimates of both distributions greatly differ when they do not overlap, corroborating the ability of the continuous interfaces to capture substantially more temporal variation of VR sickness than the CSQ-VR, which only provides sparse measurements at discrete time points. Whenever they overlap, both estimates show the similar tendency, supporting the comparability of the interfaces with the standardized questionnaire. Additional examples are provided in S.3 in the supplementary material.

residuals, p < 0.001 and p = 0.004, respectively), motivating a non-parametric analysis. Friedman tests did not reveal a statistically significant effect of interface condition for either metric (IR: $\chi^2(2) = 3.29$, p = 0.19; Number of changes: $\chi^2(2) = 3.48$, p = 0.18). While uncorrected post-hoc comparisons suggested trend-level differences (IR: Halos vs. Bars, p = 0.075; Number of changes: Halos vs. Dials, p = 0.049), none of these effects survived Holm correction for multiple comparisons. Notably, the IR associated with the standardized questionnaire (on the order of 2×10^{-4}) was substantially lower than that of all interface conditions, and the questionnaire can yield at most two detectable changes. This is expected, as the questionnaire captures user input at only three discrete points in time, whereas the interactive interfaces enable continuous information transmission throughout the task (see Fig. 3).

O3. User experience comparison. SUS questionnaire results indicate that the Bars interface achieved the highest usability score, followed by Dials, while CSQ-VR received the lowest rating (Bars=90.4; Dials=88.8; Halos=86.1; CSQ-VR=74.5). Interestingly, ranking data obtained from the interviews identified the Dials interface as the participants' favorite (Dials=63; Bars=50; Halos=37). Finally, comfort ratings on a 7-point Likert scale followed the same trend, favoring Dials and Bars over the Halos interface. This confirms the preference of continuous interfaces over discrete questionnaires.

5 Conclusions and limitations

Our work is a step towards the development of continuous real-time tools for assessing immersive sickness during VR experiences, without introducing disruption. Our quantitative analyses show that all of our three interactive interfaces achieve comparable performance in terms of estimation accuracy and information transmission, offering similarly reliable and efficient sickness measurements, with all of them being superior to commonly-used standard questionnaires.

Together with the subjective reports (see the qualitative feedback from semi-structured interviews in S.4 of supplementary material), our results indicate that the Dials interface offers the best overall balance between usability, comfort, and user preference, with Bars representing a close alternative. Moreover, participants further reported that interaction with interface did not disrupt their sense of presence or immersion and was perceived as less intrusive than interrupting the experience to complete questionnaires. The standardized questionnaire, by contrast, was consistently rated lower and exhibited substantially lower information rates. This supports our hypothesis that continuous real-time self-report enables richer characterization of symptom dynamics (see Fig. 3) than discrete questionnaire-based assessments, which are inherently limited to sparse time points.

Our work is not free from limitations; as with other similar studies, a more diverse set of scenes should be analyzed, to study how well our conclusions generalize. For these analyses, our work does provide a tested methodology. Future work could also include other immersive techniques such as AR or MR. Moreover, we have recorded physiological measurements (e.g. Galvanic Skin Response, eye tracking, head movement), which we plan to analyze to complement subjective assessments and explore objective-subjective relationships as well as investigate potential temporal lag between symptom recognition and reporting.

In summary, real-time monitoring of sickness may unlock a particularly promising research direction: the adaptation of the stimulus intensity (such as speed or acceleration in a VR scene) based on real-time symptom reports, with the goal of providing a more pleasant experience adapted to each particular user. In addition, we hope that our work helps other researchers, providing a tested means to collect detailed temporal characterization of VR sickness while providing new opportunities for evaluating and designing safer and more comfortable immersive experiences.

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