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Predicting virtual reality discomfort

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Abstract

Purpose: Virtual Reality (VR) headsets are becoming more and more popular and are now standard attractions in many places such as museums and fairs. Although the issues of VR induced cybersickness or eye strain are well known, as well as the associated risks factors, most studies have focused on reducing it or assessing this discomfort rather than predicting it. Since the negative experience of few users can have a strong impact on the product or an event's publicity the aim of the study was to develop a simple questionnaire that could help a user to rapidly and accurately self-assess personal risks of experiencing discomfort before using VR.

Methods: 224 subjects (age 30.44±2.62 y.o.) participated to the study. The VR experience was 30 minutes long. During each session, 4 users participated simultaneously. The experience was conducted with HTC Vive. It consisted in being at the bottom of the ocean and observing surroundings. Users could see the other participants' avatars, move in a 12 m^2 area and interact with the environment. The experience was designed to produce as little discomfort as possible. Participants filled out a questionnaire which included 11 questions about their personal information (age, gender, experience with VR, etc.), good binocular vision, need for glasses and use of their glasses during the VR session, tendencies to suffer from other conditions (such as motion sickness, migraines) and the level of fatigue before the experiment, designed to assess their susceptibility to cybersickness. The questionnaire also contained three questions through which subjects self-assessed the impact of the session on their level of visual fatigue, headache and nausea, the sum of which produced the subjective estimate of "VR discomfort" (VRD). 5-point Likert scale was used for the questions when possible. The data of 29 participants were excluded from the analysis due to incomplete data.

Results: The correlation analysis showed that five questions' responses correlated with the VRD: sex ($r = -.19$, $p = .02$ (FDR corrected)), susceptibility to head aches and migraines ($r = -.25$, $p = .002$), susceptibility to motion sickness ($r = -.18$, $p = .02$), fatigue or a sickness before the session ($r = -.26$, $p < .002$), and the stereoscopic vision issues ($r = .23$, $p = .004$). A linear regression model of the discomfort with these five questions as predictors ($F(5, 194) = 9.19$, $p < 0.001$, $R^2 = 0.19$) showed that only the level of fatigue ($beta = .53$, $p < .001$) reached statistical significance.

Conclusion: Even though answers to five questions were found to correlate with VR induced discomfort, linear regression showed that only one of them (the level of fatigue) proved to be useful in prediction of the level of the discomfort. The results suggest that a tool whose purpose is to predict VR-induced discomfort can benefit from a combination of subjectve and objective measures.

Introduction

Over the past decade, Virtual Reality (VR) devices have seen significant improvements offering nowadays truly immersive experience and presenting a strong potential for numerous applications. Yet, associated inconveniences such as eye strain [1] or visually induced motion sickness [2, 3] have still not been solved and many users experience various levels of discomfort. For instance, at least a third of general population is expected to experience some symptoms of cybersickness and at least 5% to experience severe symptoms [4] that could affect their following activities along the day. (In this article, we refer to the general discomfort, motion sickness symptoms, ocular and other issues caused by VR use as cybersickness.)

A large body of literature exists on how to assess cybersickness [1] and its causes, highlighting he importance of different factors such as hardware parameters, Virtual Environment (VE) and individual susceptibilities (for reviews see [4, 5, 6, 3, 7]). However, despite the importance of individual factors, recommendations to protect users from being inconvenienced are still very basic (e.g. "not suitable for under 12 y.o.", 3-levels comfort scale for games). In view of the importance of cybersickness on the use and acceptance of VR products, the aim of this study was to assess if a simple questionnaire, based on these individual factors, could be developed to allow users to self assess the risk of experiencing discomfort beforehand with better accuracy.

Methods

Apparatus and procedure

The VR experience used in this study was developed as a part of an interactive attraction at a scientific fair dedicated to marine wild life by local museum Océanopolis, Brest, France. VR sessions took place in a hall with space of 12 m^2 designated to the participants. Each session took approximately 30 min.

The VR sessions were administered using HTC Vive, HTC Coroporation system (1080 x 1200 pixels per screen, 90 Hz, 110° field of view). The system consisted of a headset attached to a transportable computer strapped to the subject's back.

The VR experience was a sequence of scenes with teleportation-like transitions [8] between them. Scenes followed a predefined scenario and consisted of static landscape and moving imagery with occasional pointing tasks. The VE was administered for groups of four users, observers saw the avatars of other co-participants and the projection of their own hands.

The VE was presented monoscopically, parallax was the only available depth cue. Even though subjects were allowed to move freely within the designated area, very little translational motion actually was necessary and took place. No translational movement was present in the scenario. Overall, the virtual experience was rather mild. Therefore, rather low cybersickness scores were expected.

Questionnaire

The list of questions is presented below. The questionnaire was written in French. Here we present English translations. The questionnaire was divided into two groups. The first aimed to assess the predictors, and the purpose of the second group was to assess the symptoms. The first group included the questions 1-11. The answers for all 5-point Likert scale questions were counted as 1 for extreme "Yes" and 5 for extreme "No".

(1) "Sex" - Male/Female. This question was motivated by the studies showing more severe symptoms in women, as evident from higher drop-out rate [9, 10].

(2) "Age" - Numerical. Age could be a factor, since Park et al. [10] found increased drop-out rate in older group.

(3) "Do you wear glasses?" - Yes/No, (4) "If yes, did you have to take them off to put the headset on?" - Yes/No. Uncorrected refractive error causes eye strain [11] which could be a reason for some of the symptoms of cybersickness. Also, wearing glasses inside the headset chamber would intensify interpupillary distance mismatch, which has been shown to cause cybersickness [12], since the spectacle lenses would extend closer to the centres of the headset lenses.

(5) "How many times have you used a VR headset before?" - Numerical. The purpose of this question was to assess the effect of habituation which has been demonstrated to alleviate symptoms [13, 14] (up to a point where habituation is considered the best if not the sole reliable treatment for motion sickness symptoms [15]).

(6) "Do you often have headaches or migraines?" - 5-point Likert scale. While migraine sufferers are known to be susceptible to motion sickness [15], Paroz and Potter found similarities in migraine and cybersickness triggers [16].

(7) "Are you sensitive to motion sickness (car sickness, sea sickness, etc.)?" - 5-point Likert scale. Motion sickness history was shown to be related to higher occurency of cybersickness [12].

(8) "Are you ill or tired?" - 5-point Likert scale. LaViola is his review [17] proposes illness and fatigue as an important individual factor.

(9) "Do you have difficulties keeping balance?" - 5-point Likert scale. This question provides an estimate of individual postural instability. Risi and Palmisano [18] found that subjects who experienced cybersickness symptoms had higher spontaneous postural activity (SD of centre of foot pressure) measured before the VR session. Even though Arcioni et al. [19] did not find differences in SD of postural sway, sway area was significantly higher for those who would experience cybersickness.

(10) "Do you see well with both eyes (with or without glasses)?" - 5-point Likert scale. This question was an addition to questions (3) and (4) inquiring about possible reasons for eye strain.

(11) "Do you see well in 3D (e.g., stereogramms or in 3D cinema)?" - 5-point Likert scale. This question was aimed at assessing the mismatch in binocular perception. For instance, Shibata et al. [20] found the connection between visual discomfort caused by accommodation-vergence conflict and the level of phoria and zone of clear single binocular vision. Hale and Stanney [21] expressed concerns about possibility of worse cybersickness symptoms due to oculomotor disturbances caused by mismatch in oculomotor cues.

Following four questions were introduced as measure of discomfort caused by the VR experience. However, only first three were used in formal analysis. We used the sum of their scores as a measure of presence of cybersickness symptoms.

(12) "Did this experience cause you eye discomfort or visual fatigue (dry eye sensation, etc.)?" - 5-point Likert scale.

(13) "Did this experience cause you headache or migraines?" - 5-point Likert scale.

(14) "Did this experience cause you general discomfort (nausea, dizziness, etc.)?" - 5-point Likert scale.

(15) "Did you like the experience?" - 5-point Likert scale.

Subjects

Visitors of the fair freely participated in the attraction. Immediately upon finishing a session, all subjects were approached by an experimenter and informed about an opportunity to take part in a scientific study. After the VE, they were free to take a questionnaire form off a table where they were stored and put the filled out forms into a designated area. 224 subjects participated in the study (age M = 30.1, 95% CI: 27.44-32.78).

Results

Results of 24 subjects were discarded from further analysis due to incomplete data. Out of 195 remaining subjects, 45 reported some discomfort.

For the analysis purposes, for each subject discomfort score was calculated as the sum of questions (12)-(14) in order to use Spearman's correlation and linear regression [22]. In order to first identify factors that had a relation to post-session VR-induced discomfort, we calculated Spearman correlation indices and significance levels (FDR correction applied) between the discomfort score and each of predictor questions (1)-(11). The correlation analysis results for the questions with scores which had significant correlation can be found in Table 1.

The scores of the questions which relate to eye strain caused by uncorrected refraction error (3, 4 and 10) did not show significant correlation to the discomfort score. We also did not find any correlation with observer's age (2). Surprisingly, correlations with previous experience of VR use (5) and posture stability (9) also did not reach insignificance.

However, the correlation analysis showed that sex (1), history of migraines (6), motion sickness (7), fatigue or illness (8) and stereoscopic vision dysfunctions self-report (11) were significantly correlated to the discomfort score (see Table 1).

We proceeded by building a linear regression model with cybersickness score as dependent variable and with the scores of the questions that correlated significantly with the cybersickness score as independent variables. The model was found to be significant ($F(194) = 9.19$, $p < .001$, $R^2 = .19$) and revealed only one significant factor among predictors which happened to be (8) fatigue or illness ($\beta = -.53$, $p < .001$). In view of the discrepancy

Question number and interpretation	Spearman ρ	p (FDR)
1. Higher incidence of cybersickness symptoms in women	-.19	.02
6. Higher cybersickness score in migraine sufferers	-.25	.002
7. Higher cybersickness in motion sickness sufferers	-.18	.02
8. Tired subjects tended to have higher cybersickness score	-.26	.002
11. Subjects with good stereoscopic vision were less susceptible to cybersickness	.23	.004

Table 1. Correlation analysis results. The index and the significance of correlation between the cybersickness score and each question were calculated. Only factors with statistically significant correlations are shown. p-values are FDR-corrected

in correlation and regression analysis results and rather low R^2 value, we performed regression assumption tests and found that residuals normality assumption was violated (Shapiro-Wilk's W = 0.75, $p < .001$). We concluded that the regression model was invalid due to the fact that the majority of subjects did not report any cybersickness symptoms.

Discussion

While the issue of cybersickness has not been resolved yet, different strategies were adopted in regard to virtual reality headset usability. Discomfort issues are still inherent to VR experience and continue to limit its adoption. Different strategies are implemented to reduce it and fully enjoy the promising potential of VR headsets. The main approach is, probably, hardware and software improvement, for instance reducing head tracking lag or image flicker, or using eye tracking to blur the image in the peripheral field so as to simulate a more natural vision. These developments are guided by research into the causes for individual susceptibility to cybersickness.

We are, however, still far from fully understanding the cause of cybersickness and how it can be mitigated [23] and such studies are useful to gain insights into the nature of the fundamental mechanisms causing cybersickness or to single out individuals who are at particular risk of suffering severe symptoms (see research on postural stability [19, 18]).

The present study's main goal was to develop a questionnaire which would allow predicting the level of symptoms based on a participant's responses to a short series of questions concerning their susceptibility factors.

The correlation analysis performed in this study confirmed the higher effect of VR use on women (question 1) [9, 10], on people suffering from migraines (question 6) [15, 16] and on people with history of motion sickness (question 7) [13, 14]. The analysis also showed a significant relation to fatigue or sickness (question 8) [17]. It is worth noting that the VE in our study was milder than more provocative ones employed in the majority of the studies, therefore the members of our sample who felt the symptoms are guaranteed to suffer from cybersickness in the majority of VR experiences.

A rather novel finding was the importance of stereoscopic vision issues (question 11). To our knowledge, no studies have looked at the link between cybersickness symptoms and binocular vision issues. The discomfort could result from inefficient use of depth cues or intensified sensory conflict, e.g., between accommodation and vergence or between expected and actual movement of stimuli in depth. A possible prospect study could probe cybersickness profile peculiarities [24] emerging in different stereoscopic vision malfunctions.

We hoped that with the factors that we identified could define a linear model capable of accurate predictions of the chances of experiencing the discomfort. Unfortunately, as evident from the non-normal distribution of the residuals, the nature of the data did not allow for a high precision regression model. Only fatigue (question 8) appears useful as a predictor. A possible reason for this could be the low cybersickness symptom occurrence rate (22.5%) and, ultimately, mild effect of VR experience. Another explanation for significant correlations between cybersickness score and individual factors, which did not reach significance as predictors in the regression model, could point at existence of different separate mechanisms causing cybersickness symptoms. These hypothetical mechanisms could stem from different individual susceptibilities causing discomfort only to users suffering from them. For instance, subjects suffering from postural instability would experience cybersickness symptoms in VE provoking dynamic postural responses, whereas subjects with oculomotor dysfunctions would be subject to severe symptoms in VE with provoking depth cues. It would also suggest that, depending on the individual susceptibility of a given user, different mitigation techniques could be applied to a given VE for them to be the most beneficial in symptom reduction. In this regard, looking at cybersickness symptom profile differences between subjects with different susceptibilities could provide valuable information.

In terms of understanding the general mechanism causing cybersickness, given none of the questions related to the eye strain caused by refractive error showed correlation with the cybersickness score, our results provide evidence supporting the claim of lower importance of oculomotor symptoms in cybersickness [24]. However, the link between cybersickness symptoms and binocular vision issues also found in this study (question 11) allows to suppose that there are still some aspects of the oculomotor system that demand attention in respect to the development of the cybersickness symptoms. The question aiming at assessing the posture stability used in this study failed to demonstrate significant correlation, whereas objectively measured postural sway was shown to predict which subjects would feel the symptoms [18, 19]. This contradiction demonstrates the usefulness of objective measures, such as postural sway measurement for postural stability and eye movements for stereoacuity, for future applications. However, even though the use of a subjective method is an obvious limitation to our study, a portion of individual factors presumed to affect the cybersickness symptoms cannot be measured objectively and require a questionnaire. The study of cybersickness could profit from a tool assessing a wider range of possible effects both for the purpose of development of full understanding of factors in play in cybersickness and in order to prematurely identify the users who would have it worst. Such a tool would benefit from a combination of objective and subjective measures.

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