Revising the factor structure of the Simulator Sickness Questionnaire

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Cybersickness (McCauley & Sharkey, 1992), or more appropriately, virtual reality induced symptoms, is the term commonly used to describe the temporary side-effects caused by an immersion in virtual reality. Cybersickness does not represent a disease but rather a normal physiological response to an unusual stimulus (Lawson, Graeber, Mead & Muth, 2002). Following McCaulay and Sharkey's 1992 paper, cybersickness is often compared to motion sickness, although Cobb, Nichols, Ramsey and Wilson (1999) and Lawson et al. (2002) argued that the aetiology of the side-effects of immersions in virtual reality is significantly different. Typical symptoms include nausea, dizziness, headache, eyestrains, blurred vision, vertigo, difficulties keeping balance, sweating and general discomfort.

Reviewing the literature about the side effects of virtual reality is complex because side effects are caused by several factors, many of which depend on the technology used (e.g., HMD vs CAVE technology, weight and field–of-view of the HMD, or speed and accuracy of motion trackers and computers), the task performed by the user (e.g., intensity of motion and head movement), and individual differences (e.g., people from the general population vs highly trained military personnel) (Cobb et al., 1999; Frey, Harting, Ketzel, Zinkernagel & Moosbrugger, 2007; Golding, 2006; Lawson et al., 2002; Nichols & Patel, 2002). Since a detailed literature review on cybersickness is outside the scope of this paper, the reader must keep in mind that incidence rates of virtual reality side effects can vary significantly according to the aforementioned factors.

Symptoms of cybersickness appear to be common among people immersed in virtual reality. In general, about 5% of the users do not experience any side-effects and 5% experience side-effects so strong that they have to stop the immersion (Lawson et al., 2002). Cobb et al. (1999) and Wilson (1997) summarized the results of a comprehensive research program conducted with 148 civilians and 75 non-civilians using a variety of virtual environments, tasks and equipment and for immersions that varied between 20 to 120 minutes. They found that 20% of their civillan participants did not notice any side-effects. Among the remaining participants, only a few (5% of the total sample) experienced side effects severe enough that they had to stop the immersion. The other participants reported side-effects that, usually, were mild and subsided within 10 minutes after the immersion. Symptoms usually occurred within the first 15 minutes of the immersion. Howarth and Finch (1999) assessed nausea symptoms every minute with 14 civilians immersed for 20 minutes in a virtual environment. They found a progressive increase of symptoms over time, followed by a steep reduction after the immersion. Using data collected during 938 military flight simulations, Kennedy, Stanney and Dunlap (2000) demonstrated that longer immersions (sometimes more than three hours) progressively induced more side-effects and that symptoms tend to be less severe after a few repeated immersions.

The dominant theory for virtual reality induced side-effects is the sensory conflict theory (Golding, 2006; Oman, 1982; Reason, 1978). This theory proposes that symptoms occur during immersions primarily as a result of conflicts between three sensory systems: visual, vestibular and proprioceptive. An example of conflicting stimuli during an immersion would be if, while wearing a HMD, the eyes perceive a head movement that is out of sync by a few milliseconds with what is perceived by the vestibular system, whereas the remainder of the body remains almost motionless. This theory has been questioned (Stoffregen & Riccio, 1991) and alternative explanations have been proposed, such as the postural instability theory (Bonnet, Faugloire, Riley, Bardy & Stoffregen, 2006; Riccio & Stoffregen, 1991). Since this is not a matter of wide debate in the literature, the debate is still open.

Although a few instruments exist to measure virtual reality induced side effects (e.g., Ames, Wolffsohn & McBrien, 2005; Golding, 2006; Lawson, 1993), the Simulator Sickness Questionnaire (SSQ) from Kennedy, Lane, Berbaum and Lilienthal (1993) is the most-often used instrument to measure virtual reality induced side effects. The symptoms of the SSQ are supposed to form three factors: nausea (e.g., vomiting, dizziness), oculomotor (e.g., eyestrains, blurred vision, headaches), and disorientation (vertigo, imbalance). The factor structure of the SSQ is based on the Kennedy et al. (1993) study with a sample of 1,119 military participants who were immersed in a variety of Navy simulator training exercises. The original pool of items and the scoring method were drawn from the Motion Sickness Questionnaire (Kellogg, Kennedy, & Graybiel, 1965). Kennedy et al. (1993) performed a principal factor analysis with varimax rotation and, after comparing factor solutions with three to six factors, concluded that a three factor solution was the most interpretable. They observed that a large portion of their sample had very few symptoms, so the analysis was repeated with approximately 600 observations from the five simulators that induced the most symptoms. The three factor structure was confirmed, along with the existence of a second-order more general factor.

Unfortunately, as Kennedy et al. (1993) noted, many items of the SSQ load significantly on more than one factor. Therefore, some items are scored on two different subscales and, following the Kennedy et al (1993) scoring procedure, are scored twice in the calculation of the total score. The items "general discomfort" and "difficulty concentrating" were assigned to both the nausea and oculomotor subscales, and the items "difficulty focusing" and "blurred vision" were assigned to both the oculomotor and disorientation subscales. Given the slightly blurred factor structure of the SSQ and, most importantly, the fact that it was administered to military participants using simulators, the current factor structure of the SSQ may not be adequate for research and treatment using virtual reality with a population of adults from the general public. The goal of the study was therefore to assess the factor structure of the SSQ with a sample of people drawn from the general population, including people suffering from anxiety disorders.

METHODS

Sample

The sample consisted of 371 adults (71% female) recruited from the general population either for research on anxiety disorders (n = 164 received a DSM-IV diagnosis based on a structured clinical interview) or experiments with "normal controls" (n = 207 screened for the absence of anxiety disorders based on a structured clinical interview). Among the 164 anxious participants, the most frequent diagnosis was specific phobia, followed by social phobia, generalized anxiety disorder, panic disorder with agoraphobia and post-traumatic stress disorder. The mean age was 35.2 (s.d. = 12.96, range from 18 to 68).

The project was approved by the Research Ethics Board and participants had to remain in the waiting room 15 minutes after the immersion before leaving the laboratory. While in the waiting room they received a handout describing what cybersickness is and contact information in case they experienced after-effects or prolonged side-effects.

Measures

Simulator Sickness Questionnaire (Kennedy et al., 1993) (SSQ). It consists of 16 items listing virtual reality side effects rated from "0" (none) to "3" (severe). A French translation of the SSQ was used in this study. The instrument was first translated from English to French by the authors of this paper. The translation was further reviewed by bilingual psychologists in order to obtain independent assessments of the quality of the translation. Following Kennedy et al.'s (1993) recommendation, the SSQ should be first administered prior to the immersion in order to rule-out symptoms that could be already present prior to the immersion, and then administered post-immersion. Data collected at the pre-immersion were not used for the current study since most participants scored zero on all items. Only post-immersion data were analyzed and, in the case of participants who were immersed in virtual reality more than once, only data collected after the first immersion were used. If participants had to stop the immersion because of severe side-effects, the SSQ was completed immediately. The Cronbach's alpha for the SSQ in the current sample was .87.

Table 1. Corrected item-total correlations for the SSQ in this sample.

SSQ Items	Item-total correlations
General discomfort	.65
Fatigue	.42
Headache	.53
Eyestrain	.48
Difficulty focusing	.54
Increased salivation	.37
Sweating	.36
Nausea	.60
Difficulty concentrating	.52
Fullness of head	.61
Blurred vision	.45
Dizzy (eyes open)	.53
Dizzy (eyes closed)	.62
Vertigo	.47
Stomach awareness	.52
Burping	.42

Corrected item-total correlations were all satisfactory (see Table 1).

Structured Clinical Interview for DSM-IV (First, Spitzer, Gibbon, & Williams, 2000). This is a semi-structured interview used for screening every participant and diagnosing mental disorders according to DSM-IV criteria (APA, 2000).

Presence Questionnaire and **Immersive Tendencies Questionnaire** (Witmer & Singer, 1993). Presence was measured with these frequently used instruments. The 24 items of the Presence Questionnaire were scored according to Witmer and Singer's (1993) recommendation. The Immersive Tendencies Questionnaire assesses an individual's proneness to experience presence in a virtual environment. The 19 items were scored according to Witmer and Singer's (1993) recommendation. French versions of these two instruments were used to describe the sample. The average score on the Immersive Tendencies Questionnaire was 70.29 (s.d. = 14.79) and the average score on the total score of the Presence Questionnaire was 90.32 (s.d. = 15.84).

Brief rating of anxiety. After the first five minutes of immersions, participants were asked verbally to rate on a "0" to "10" scale the intensity of their anxiety "right now". The brief verbal assessment was performed in order to correlate anxiety with items of the SSQ. The brief anxiety rating was collected only on 132 of the 164 participants who were diagnosed with an anxiety disorder.

Material

In order to maximize the generalization of the results, participants were immersed in virtual reality with different technologies (HMD, CAVE-like), different HDM (I-Glass, Cy-Visor, nVis, V8, Visettre-pro), different trackers (Intertrax^2 , Inertia CUBE, IS-900), and performed different tasks (i.e., exposure to feared stimuli, exploration, attention) and for different durations (immersions lasted between 5 to 60 minutes).

RESULTS

A principal factor analysis was performed, followed by a varimax rotation. The number of factors was assessed based on three criteria: eigenvalue higher than one, the scree-plot test and the interpretability of the factor solution (including reducing cross-loadings to a minimum). The eigenvalue criteria pointed towards a three-factorial solution but between two to four factors were examined. The three factor solution was appealing, but the number of cross leadings was high (5 items loaded higher than .40 on two factors). The two-factor solution was clear and interpretable. All loadings were larger than .40, with no cross-leadings, with nine items on Factor 1 and seven on Factor 2 (see Table 2). To substantiate our decision to retain the two-factor model, the quality of fit of both our two-factor model and the three-factor model suggested by Kennedy et al. (1993) were put to the test with two indices used in structural equation modeling to compare models, the Akaike Information Criteria (AIC) and the Bayesian Information Criteria (BIC). Both indices document the parsimony of a model by assessing how well it fits the data and adjusting for the complexity of the model. The AIC is based on the number of parameters estimated and the maximum likelihood function, where a good fit obtained with a simpler model will lead to a lower AIC value than a more complex model or a worse fit. The BIC uses a Bayesian approach and gives more weight to the number of observations and penalizes overfitting more severely than the AIC does. In both cases, there is no significance test to interpret AIC and BIC; the lower the value the better. The AIC showed that the two-factor model provided a better fit of the data than the three-factor model (AIC = 354 vs 369, respectively), information that was confirmed with the BIC (BIC = 498 vs 536, respectively). Separate factor analyses were also performed for the clinical and the non-clinical sample and they matched with the factor model found with the entire sample. The only significant difference between the factor structure obtained with each sample was that the order of the two factors was reversed (i.e., Factor 1 became Factor 2 in the clinical sample).

Our results suggest that, in our sample and with a French translation, the SSQ items belong to two distinct but correlated (Pearson r = .56, p < .001) factors. The first factor consisted of items 1, 6, 7, 8, 12, 13, 14, 15 and 16 and was characterized by Nausea symptoms. The second factor was about Oculomotor symptoms and was made of items 2, 3, 4, 5, 9, 10 and 11 from the original SSQ.

The total SSQ score in the current sample was 5.03 (s.d. = 5.42, range between 0 and 42). Participants suffering from an anxiety disorder scored higher (M=6.72, s.d. = 5.9) than those who do not suffer from an anxiety disorder (M=3.86, s.d. = 4.6) [$t_{(369)}$ = 5.5, p < .001]. The subscale scores were 2.07 (s.d. = 3.14) for the Nausea factor and 2.95 (s.d. = 2.99) for the Oculomotor factor.

The brief verbal rating of anxiety after five minutes of immersion correlated significantly at p <.01 with items 2 (r = .23), 3 (r = .27) and 10 (r = .29), and at p <.05 with items 1 (r = .18) and 9 (r = .17). For these items, there may be an overlap between anxiety and cybersickness symptoms. The correlation between the SSQ and the Presence Questionnaire was very low

Table 2. Factor structure of the French SSQ in the current sample. N = 371.

Items	Factor 1 Nausea	Factor 2 Oculomotor
General discomfort	.70	
Fatigue		.44
Headache		.56
Eyestrain		.72
Difficulty focusing		.76
Increased salivation	.54	
Sweating	.61	
Nausea	.67	
Difficulty concentrating		.51
Fullness of head		.66
Blurred vision		.79
Dizzy (eyes open)	.52	
Dizzy (eyes closed)	.63	
Vertigo	.62	
Stomach awareness	.69	
Burping	.48	

Note. Factor loadings lower than .40 are not reported.

(r = -.02, ns), as well as with the Immersive Tendencies Questionnaire (r = -.06, ns).

DISCUSSION

The aim of this study was to examine the factor structure of the SSQ in a population that is closer than Navy military personnel to what researchers and clinicians using virtual reality are likely to encounter in the general population. As pointed-out by Lawson et al. (2002), military personnel may be less likely to experience cybersickness as they could be involved more frequently in challenging vehicle motion, be in better physical shape or be able to remain immersed in virtual reality longer despite feeling side-effects.

Our results suggest that the SSQ was comprised of two factors (Nausea and Oculomotor).

These two factors were very clear, included all items and did not involve cross-loadings. This is different from the known factor structure of the SSQ, where a third Disorientation factor was found by Kennedy et al. (1993). Comparison with our two-factor solution and Kennedy et al., (1993) three factor solution revealed that a two-factor model was more parsimonious (an adequate fit with less parameters). How to account for these differences? It is our opinion that the difference in factor structure is related first to the sample used (military vs general-population), and also to the kind of tasks performed (Navy simulations vs exploration or exposure to anxiety situations) and to the equipment used (VR and CAVE-like system vs flight simulator). But some limitations must be addressed before such a conclusion is reached. First, the current study was performed with a French-Canadian sample using a translated version. Even if this limit is minimal because cultural differences with the United-States are small and the translation of physical symptoms is pretty straightforward, this option cannot be ruled-out until this study is replicated. Nevertheless, it is important to highlight that our study confirms Kennedy et al.'s (1993) work on the reliability of the SSQ, with a high internal consistency and a factor structure to which all items are contributing significantly.

Further studies are necessary to assess if the Oculomotor factor is specifically related to the technology used to display the images, such as resolution and weight of the HMD or image clarity, and if the Nausea factor is more relevant to sensitivity to postural imbalance or in reaction to the tasks performed during the immersion. Factor analytic studies should compare large samples of participants from the general population immersed using different technologies (e.g., HMD vs CAVE) or under different kinds of tasks (e.g., exposure to feared situations vs exploration). The overlap between anxiety symptoms and virtual reality induced side-effects should also be examined. A strategy would be to administer post-immersion a measure of anxiety and the SSQ and examine which items load on similar factors.

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