THE REPUBLIC OF TURKEY
BAHCESEHIR UNIVERSITY

PSYCHOMETRIC EVALUATION OF SIMULATOR SICKNESS QUESTIONNAIRE AND ITS VARIANTS AS A MEASURE OF CYBERSICKNESS IN CONSUMER VIRTUAL ENVIRONMENTS

Master's Thesis

VOLKAN SEVİNÇ

İSTANBUL, 2019

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ABSTRACT

PSYCHOMETRIC EVALUATION OF SIMULATOR SICKNESS QUESTIONNAIRE AND ITS VARIANTS AS A MEASURE OF CYBERSICKNESS IN CONSUMER VIRTUAL ENVIRONMENTS

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Cybersickness, i.e. visually induced motion sickness, remains as a negative effect that is detrimental to the user experience of virtual environments (VE) developed for virtual reality (VR) consumers. As the VR technology evolves, it is rather triggered by application aspects rather than hardware limitations. For this reason, there is still a need for a measurement method to assess and compare VEs for cybersickness effects.

Simulation Sickness Questionnaire (SSQ) is used for measuring users' level of sickness symptoms and is highly appreciated in VR research. However, it is criticized for its psychometric qualities and applicability in VR, as a measure of cybersickness. Recently, two variants of SSQ were offered for measuring cybersickness, Cybersickness Questionnaire (CSQ) and Virtual Reality Sickness Questionnaire (VRSQ). There is also another variant with a different factor structure, which is called FSSQ, that is based on French translation of SSQ.

The study presented in this master thesis compares SSQ and these variants for their psychometric qualities; construct validity, discriminant validity, internal reliability, test-retest reliability and sensitivity to distinguish application aspects of VEs that are related to cybersickness. Using a within subjects experiment design, 7 different VEs with 32 participants through 9 sessions were evaluated, resulting with 288 responses to the 16-item SSQ. Results suggested that both VRSQ and CSQ were valid and reliable measures of cybersickness, as well as being sensitive to application aspects such as translational and rotational movements required by users for navigation in VEs. Compared to SSQ and FSSQ; the cybersickness questionnaires, CSQ and VRSQ, revealed better indicators of validity. On the other hand, it is assumed that the development of the two cybersickness scales had limitations in sample size to represent VR consumers and limitations in stimuli to represent the applications aspects of consumer VEs. The evaluation of SSQ symptoms with larger samples and broader range of applications to identify the symptoms and the construct of a subjective measurement tool is further suggested.

Keywords: Cybersickness, Virtual Reality, Visually Induced Motion Sickness, Questionnaire, Scale, Psychometric Evaluation.

ÖZET

SIMÜLASYON HASTALIĞI ANKETİ VE VARYASYONLARININ TÜKETİCİ ORTAMLARINDA SİBER HASTALIK ÖLÇÜTÜ OLARAK PSİKOMETRİK DEĞERLENDİRİLMESİ

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Siber hastalık, yani görsel olarak indüklenen hareket hastalığı, sanal gerçeklik (VR) tüketicileri için geliştirilen sanal ortamların (VE) kullanıcı deneyimine zarar veren olumsuz bir etki olarak kalır. VR teknolojisi geliştikçe, donanım kısıtlamaları yerine uygulama yönleri tarafından tetiklenir. Bu nedenle, VE'leri siber hastalık etkilerine karşı değerlendirmek ve karşılaştırmak için bir ölçüm yöntemine hala ihtiyaç vardır.

Simülasyon Hastalığı Anketi (SSQ), kullanıcıların hastalık belirtileri düzeyini ölçmek için kullanılır ve VR araştırmalarında büyük değer verilir. Bununla birlikte, siber hastalılığın bir ölçüsü olarak, psikometrik nitelikleri ve VR'deki uygulanabilirliği nedeniyle eleştirilmektedir. Son zamanlarda, siber hastalığın, Siber Hastalık Anketinin (CSQ) ve Sanal Gerçeklik Sorunlarının Anketinin (VRSQ) ölçülmesi için iki SSQ çeşidi sunulmuştur. Ayrıca, SSQ'nun Fransızca çevirisine dayanan FSSQ olarak adlandırılan farklı bir faktör yapısına sahip başka bir değişken daha vardır.

Bu yüksek lisans tezinde sunulan çalışma SSQ ve bu değişkenleri, psikometrik nitelikleri için karşılaştırıyor; geçerlilik, ayırt edici geçerlilik, iç güvenilirlik, test-tekrar test güvenilirliği ve siber hastalıkla ilgili VE'lerin uygulama yönlerini ayırt etmek için hassasiyet oluşturmak. Bir konu içi deney tasarımı kullanılarak, 9 oturumda 32 katılımcıyla 7 farklı VE'da değerlendirildi ve 16 maddelik SSQ'ya 288 cevap verildi. Sonuçlar, hem VRSQ hem de CSQ'nun geçerli ve güvenilir bir siber hastalık ölçütü olduğunu ve aynı zamanda kullanıcıların VE'lerde navigasyon için gereken çeviri ve rotasyon hareketleri gibi uygulama yönlerine duyarlı olduklarını göstermiştir. SSQ ve FSSQ ile karşılaştırıldığında; Siber hastalık anketleri CSQ ve VRSQ, geçerlilik göstergelerinin daha iyi olduğunu ortaya koydu. Öte yandan, iki siber haslık ölçeğinin geliştirilmesinin, VR tüketicilerini temsil etmek için numune boyutunda ve tüketici VE'lerin uygulama yönlerini temsil etmek için teşvik edici sınırlamalara sahip olduğu varsayılmaktadır. Semptomları ve subjektif bir ölçüm aracının yapısını tanımlamak için SSQ semptomlarının daha geniş örneklerle ve daha geniş uygulama alanlarıyla değerlendirilmesi önerilmektedir.

Anahtar Sözcükler: Siber Hastalık, Sanal Gerçeklik, Görme Kaynaklı Hareket Hastalığı, Anket, Ölçek Psikometrik Değerlendirme.

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ABBREVIATIONS

AIC	:	Akaike Information Criterion
ANOVA	:	Analysis of Variance
AVE	:	Average Variance Extracted
BIC	:	Bayes Information Criterion
CFA	:	Confirmatory Factor Analysis
CFI	:	Comparative Fit Index
CSQ	:	Cybersickness Questionnaire
CV1	:	Oculus Rift Customer Version 1
D	:	Disorientation
F-SSQ	:	French translation of SSQ
F-SSQ-N	:	French translation of SSQ – Nausea
F-SSQ-O	:	French translation of SSQ – Oculomotor
HMD	:	Head Mounted Display
MSQ	:	Motion Sickness Questionnaire
N	:	Nausea
O	:	Oculomotor
RMSEA	:	Root Mean Square Error of Approximation
RSSQ	:	Revised Simulation Sickness Questionnaire
SRMR	:	Root Mean Square Residual
SSQ	:	Simulation Sickness Questionnaire
SSQ-D	:	Simulation Sickness Questionnaire – Disorientation
SSQ-N	:	Simulation Sickness Questionnaire – Nausea
SSQ-O	:	Simulation Sickness Questionnaire – Oculomotor
SV	:	Spatial Velocity
TLI	:	Tucker – Lewis Index
TS	:	Total Severity
VE	:	Virtual Environments
VR	:	Virtual Reality
VRSQ	:	Virtual Reality Sickness Questionnaire
VRSQ-D	:	Virtual Reality Sickness Questionnaire – Disorientation
VRSQ-O	:	Virtual Reality Sickness Questionnaire – Oculomotor
6DoF	:	Six Degrees of Freedom
3DoF	:	Three Degrees of fredoom

1. INTRODUCTION

This master’s thesis is based on a study about the effects of sickness related to the use of virtual reality (VR) equipment, in order to understand what these effects are and whether they can be overcome or not.

In the first part of this thesis, the given literature and related studies will be investigated and then the study about the psychometric evaluation of cybersickness will be described and the results presented.

Interacting with virtual reality (VR), especially with a head mounted display (HMD) equipped system, may trigger symptoms similar to motion sickness, referred to as visually induced motion sickness (Hettinger & Riccio, 1992) or cybersickness more suitably (McCauley & Sharkey,1992; LaViola Jr., 2000). These negative effects are potentially detrimental for users’ engagement with virtual environments (VE). While HMDs became available as consumer products, manufacturers struggled with hardware limitations that might induce cybersickness, such as field of view, display resolution, refresh rate, flicker, temporal delays and input-output latency by enhancing hardware attributes such as binocular displays, inter-pupillary distance and position tracking sensors. As the commercial HMDs has overcome many of those hardware limitations today, there is a developing market of VE software for public use, especially for entertainment purposes and younger consumers are most likely to be interested in VR entertainment (Greenlight VR, 2015).

However; cybersickness, mainly based on application aspects rather than hardware limitations; remains as an issue that is potentially discomforting VR users, although there are VE design guidelines offered by researchers based on empirical evaluation (Porcino et al., 2017; Tanaka & Takagi, 2004; Jerald, 2015:209-213) in addition to some best practices suggested by developers according to professional experience *Google Design Guideline, n.d.; Oculus VR LLC, 2017; Epic Games, 2015). Therefore, there is still a need for methods to assess the cybersickness prior to the design and development of VEs.

Several methods are available to detect and measure cybersickness. Some measures are based on the aspects of VEs such as spatial velocity (So et al., 2001b); or based on physiological responses of subjects such as finger temperature (Nalivaiko et al., 2015), heart rate, respiratory rate, skin conductance, heterophoria (Rebenitsch & Owen, 2016); or based on cognitive or behavioral responses of subjects such as prolongation of reaction time (Nalivaiko et al., 2015) or postural instability (Chardonnet et al, 2017, Takada et al., 2007). However, questionnaires, which are based on self-report responses of users, are the earliest method of assessment and "often the *de facto* rating systems of choice" (Rebenitsch & Owen, 2016).

Self-report measures of cybersickness in VEs have originated from motion sickness and simulator sickness studies. The Simulator Sickness Questionnaire (SSQ) (Lane & Kennedy, 1988) was obtained from the Motion Sickness Questionnaire (MSQ) (Kennedy and Graybiel., 1965). Re-analysing MSQ data collected via simulator studies with participants employed in military, aviation and marine services; Lane and Kennedy (1988) determined 16 symptoms of motion sickness as psychometrically sound indicators of simulator sickness. SSQ symptoms indicate three constructs of simulator sickness: Nausea (N), Disorientation (D) and Oculomotor (O) effects, along with a second order more general factor as Total Severity (TS), which were largely adopted in later studies, although the factor structure of these symptoms causes some challenges in standardization (Kennedy et al., 2010)

Bouchard, Robillard and Renaud (2007) suggested a two-factor structure for SSQ, based on data compiled from non-military participants via the French translation of the 16 symptoms (F-SSQ). Factors were revised as nausea and oculomotor based on data collected from 371 participants representing "a population of adults from the general public". (Bouchard et al. 2007)

CSQ (Cybersickness Questionnaire) (Stone III, 2017) is an attempt to select the symptoms in SSQ that would appear to clearly indicate cybersickness, as some of the symptoms measured in SSQ might be triggered by cybersickness as well as other causes, such as sweating which might occur due to physical effort. Retained 9 symptoms indicated two factors: Dizziness and Difficulty in Focusing.

Kim et al. (2018) proposed the Virtual Reality Sickness Questionnaire (VRSQ), employing 9 symptoms of original SSQ to indicate Oculomotor and Disorientation constructs. Arguing that original SSQ was conceived from the data from simulator studies in early 90's, their study revised SSQ based on data collected via mobile HMD devices using four different stimuli in a within-subjects experiment design.

The original SSQ and two-factor variant F-SSQ were suggested as simulator sickness measures and the datasets used for the scale development process included several flight simulators besides VR systems. The two shorter forms, CSQ and VRSQ were proposed as cybersickness measures.

Our work aims to assess psychometric qualifications of original SSQ and these variants for measuring cybersickness in publicly available HMD VR applications. The scales are compared for indicators of reliability, validity and sensitivity; through a dataset collected from a younger group of participants who are more likely to use VR for entertainment. Data is collected within experiments conducted with seven publicly available VE applications running on a consumer HMD.

2. LITERATURE REVIEW

The usage of virtual environments becomes more widespread day by day. Virtual reality devices are used for educational purposes such as flight training simulations or other complex machine trainings. The usage of those devices for educational purposes is widening because of its cost effectiveness, in comparison to real world trainings. Virtual reality devices such as head mounted displays, also provide human beings a chance to enter virtual environments for entertainment reasons and through its possible mass production, it is right now one of the most important and popular entertainment devices. But for the academic world, there are some difficulties and obstacles to overcome in this regard about the side of effects of its usage. Those are cybersickness and motion sickness.

Cybersickness is defined as the sum of the sicknesses that can occur to a person that uses virtual reality devices in order to enter a virtual environment. This environment, may be simulations as well as videogames. In the literature, there is earlier research on this topic and the results of this research shows that, some of these known sickness syndromes caused by virtual environments are headache, fatigue, sweating, nausea, eyestrain and disorientation. Those symptoms show similarities to motion sickness syndromes.

Some studies on the topic provide early research about the possible causes for those sickness syndromes or define possible threats regarding the long-term damages the uses of virtual reality devices can cause or provide some solving solutions. According to the study of Kennedy et al. (1997), the authors have analyzed two main outcomes, that only can be tested with a long-term study: ‘’Two critical and unresolved human factors issues in these VE systems are: (1) potential sickness after exposure to VEs, and (2) transfer of maladaptive cognitive and/or psychomotor performance from VE to real-world environments with, as yet, unknown adverse legal, economic, individual, and social consequences.’’ (Kennedy et al., 1997, pp. 643).

Mousavi, Jen and Musa (2013) made a research in 2013 about the possible causes of cybersickness and studied out three theories and order related issues, they may have an effect on it, in order to explain the reason of cybersickness: ‘’ There are three theories that explain the cybersickness causes; (1) the sensory conflict theory, (2) the postural instability theory, and (3) the poison theory. There are also some other causness which are not directly related to the above theory such as, Display and technology issues, position tracking error, lag, and flicker issue. From an individual standpoint, age, gender, illness, and the position in the simulator are factors that interfering with severity of cybersickness.’’ (Mousavi, Jen, Musa, 2013, pp. 37).

There are also studies which are based on observations and have collected data with the help of questionnaires in order to measure the symptoms of cybersickness. Davis, Nesbitt and Nalivaiko (2014) first identify the symptoms, cluster them and review earlier data on the topic and suggest some measurement methods. They call for the need of objective measurement methods, such as real time experiments with the observation of a subject group with the use of pre- or post- questionnaires. ‘’The development of objective measures for cybersickness is an important step in understanding the causes and effects it can have on participants as well assisting attempts to improve the design of both the technologies involved and the environments being developed.’’ (Davis, Nesbitt, Nalivaiko, 2014, pp. 8).

The study of Howarth and Costello (1997) is a comparison of the effects of cybersickness with data of their own experiment and similar data from earlier studies. The outcomes of this experiment was that the cybersickness may be related to causalities similar to other motion sicknesses.

Other studies provide some techniques to improve the virtual environment in order to relieve the common cybersickness syndromes. So the study ‘Cybersickness in the presence of scene rotational movements along different axes’ by Lo and So (2001), states that a decrease of the symptom of nausea can be reached through the arrangement of scene movement. So suggested at the HCI International Conference in 1999 to evolve a measurement formula called ‘Cybersickness Dose Value’.

These studies of So are highly related with comparable studies of motion sickness. The motion sickness defines the more general sickness symptoms, which are almost the same as these of cybersickness, but are caused by any type of motions, for example air- or seasickness.

The similarities in the symptoms of both sickness types and the increasing of symptoms in artificial environments and former research about the relationship between motion and cybersickness, turns the focus of the investigations in the direction of the motion.
The similarities and differences between virtual and real life environments are investigated and hypothesis try to be found. Golding (2006) identifies two different types of relations to motion sickness: ''(i) those related to the stimulus (motion type and provocative property of stimulus); and (ii) those related to the individual person (habituation or sensitisation, individual differences, protective behaviours'' administration of anti-motion sickness drugs) (Golding, 2006, pp. 1). He further suggests, that other fields of investigation, such as genetics, should be involved into the research of motion sickness and the potential prevention of it.

Besides the term of cyber- and motion sickness, other words to define the phenomenon of side effects in virtual environments came up. One of them is named simulation sickness. Simulation sickness is used for the symptoms, appearing in non-natural environments.

To understand the importance and relevance of the problem in this chapter previous studies are investigated. In literature there are some different field studies about the topic, which are described below in two different sections.

RSSQ (Revised simulation sickness questionnaire) is an expansion of SSQ and evaluates simulator sickness in four dimensions, using 24 items evaluated through an eleven points Likert scale (Kim et al., 2004). In addition to 16 SSQ symptoms, RSSQ employs eight additional items that are for measuring drowsiness, visual flashbacks, awareness of breathing, confusion, vomiting, pallor, difficulty equilibrating, and muscle stiffness from strain. Besides Nausea, Oculomotor and Disorientation dimensions of SSQ, RSSQ incorporates a fourth dimension as "Strain/Confusion". Transforming the eleven point

RSSQ scores to four point SSQ scores, authors reported correlations less than 7 between the two scales' dimensions and the total score.

Bruck and Watters (2011) offered a four factor model of cybersickness assessed by a combination of self-report and physiological measures. Employing SSQ symptoms, cardiac activity measurements, respiratory rate measurements and anxiety scores in their analysis, they identified the four factors as cybersickness, vision, arousal and fatigue.

Although those scales are also variants based on SSQ, they employ additional manifest variables or different scale points. F-SSQ, CSQ and VRSQ are completely derived from SSQ symptoms.

The following part explains the psychometric qualities of SSQ, F-SSQ, CSQ and VRSQ and provides information about studies that explores the aspects of VEs related to cybersickness.

2.1 PSYCHOMETRIC QUALIFICATIONS OF SSQ AND ITS VARIANTS

Symptoms of SSQ were derived from an initial set of 28 MSQ items used to evaluate motion sickness symptoms in flight simulators (Kennedy et al., 1992). The evaluated flight simulators were ten model types such as helicopter simulators with six-degrees-of-freedom (6 DoF) moving base, fixed-base, fixed-wing and dome display simulators (Kennedy et al., 1989) used in military training.

16 retained symptoms were selected according their frequency and severity in 1119 simulator tests, in which pre-exposure and post-exposure data were collected. Symptoms that showed systematic changes from pre-exposure to post-exposure were chosen.

Although some symptoms such as vomiting are clearly important signs of motion and simulator sickness, they were not retained since they were rarely observed. Some of the excluded symptoms like boredom had high frequency but considered as misleading since they were not observed consistently with other symptoms.

A series of varimax rotated principal component analyses revealed a three factor structure as the most interpretable solution based on retained 16 symptoms. However, some symptoms generated considerable loads on multiple factors. By reason of assigning items that had a varimax loading more than 30 as an indicator of a factor, some symptoms indicated multiple factors, as seen in Table 2.1 Each cluster of symptoms reflected an impact of simulator exposure on a different system within the human body.

Transforming these three factors into a hierarchical structure, a superior general construct of simulation sickness is proposed as index of Total Severity (TS). The scores for each construct and the superior Total Severity (TS) score is calculated as follows, using sums of total scores A, B and C in Table 2.1.

$$\begin{aligned} N &= [A] \times 9.54 \\ O &= [B] \times 7.58 \\ D &= [C] \times 13.92 \\ TS &= [A] + [B] + [C] \times 3.74 \end{aligned} \qquad \textbf{(2.1)}$$

Table 2.1: Symptoms in Dimensions of Simulator Sickness and Cybersickness

	SSQ			F-SSQ		CSQ		VRSQ	
	Nausea	Oculomotor	Disorientation	Nausea	Oculomotor	Dizziness	Difficulty in focusing	Oculomotor	Disorientation
General discomfort	✓	✓		✓				✓	
Fatigue		✓			✓			✓	
Headache		✓			✓	.50			✓
Eyestrain		✓			✓		.58	✓	
Difficulty focusing		✓	✓		✓		.89	✓	
Increased salivation	✓			✓					
Sweating	✓			✓					
Nausea	✓		✓	✓		.84			
Difficulty concentrating	✓		✓		✓				
Fullness of head			✓		✓		.55		✓
Blurred vision		✓	✓		✓		.81		✓
Dizzy (eyes open)			✓	✓		.89			
Dizzy (eyes closed)			✓	✓		.99			✓
Vertigo			✓	✓		.54			✓
Stomach awareness	✓			✓					
Burping	✓			✓					
	[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]

Majority of the studies that were conducted using the SSQ only reported the TS score (Lin et al., 2002; Draper et al., 2001; Lampton et al., 2000). Several studies provided evidence that SSQ and its sub dimensions are sensitive to different display types (Garris-Reif & Franz, 1995; Häkkinen et al., 2002), system configurations (Cobb et al., 1999; Nelson et al., 2000) or simulator types (Kennedy et al., 1994). Different types of platforms, like helicopter, fixed wing, driving simulators and HMD, BOOM VR and CAVE VR systems have different SSQ profiles. Drexler (2006) reported an O>N>D profile for flight simulators while VR systems and driving simulators presented an O>D>N profile of SSQ sub dimensions. She suggested a proportional scoring approach for profile comparison of sub dimensions. In her method, each scale score was divided by sum of all three sub scores.

But still this study has some weaknesses, which were described in other studies, diving further into the literature: Bouchard et al. (2007) criticized the SSQ for its complicated factor structure and for its being developed on a dataset compiled from military professionals who were not representative of the adults from of the general public. They used French translation of 16-item SSQ, administered to 307 participants (71% female) who evaluated different HMDs with different tracking systems and a CAVE-like VR environment, utilizing several tasks such as exposure to feared stimuli, attention and exploration. Using principal axis factoring with varimax rotation, they suggested a two-factor solution that minimized cross-loading of items. Comparing their two-factor model with three-factor model of Kennedy et al.(1993) using AIC (Akaike) and BIC (Bayes) information criteria of model fit comparison, the two factor model provided better evidence for construct validity. Bouchard et al. (2007) did not provide a clear administration and scoring for F-SSQ. They reported their results as mean values for Nausea and Oculomotor factors and total score as sum of these means. The [D] and [E] values in Table 2.1 are mean values of corresponding items, and total score is calculated as [D] + [E].

Stone III (2017) hypothesized that original factor model would not fit SSQ responses in state-of-the-art consumer-oriented VR applications. Three commercially developed VEs for HMDs were evaluated by 202 participants (37% female and 68% with no prior VR experience) employing a between-subjects experimental design, using an HMD connected to a personal computer. He suggested that two of the VEs, which were a car racing game and a roller-coaster simulation, had discordant visual motion and vestibular information since the users move in the VEs by vehicular locomotion but the users' point of view is controlled by HMD position. The third VE provides a room-scale experience that locomotion is acquired by stepping in the actual room and point of the view is controlled by HMD tracking. Thus, the experience imparts a concordant visual motion and vestibular information. The data analysis based on an item-response theory approach failed to support the original three-factor structure of SSQ and the alternative models based on 16 symptoms. The author suggested that "could have been a result of a combination of sparsity (overall low symptom incidence) and inclusion of SSQ items that may not be indicative of cybersickness." To adjust sparsity by low symptom incidence, the moderate symptoms and severe symptoms were amalgamated, i.e. re- scoring the severe (3) scored items to moderate (2), which resulted in a scoring system of 0 (none), 1 (slight) and 2 (moderate). 9 items were selected among the SSQ items amongst the other alternatives and a two-factor structure (Dizziness and Difficulty in focusing) was offered which presented the best model fit. Factor scores were calculated as the sum of each amalgamated item score multiplied by its weight (see Table 2.1) as:

$$[F] = \text{sum}(\text{itemScore} \times \text{itemWeight})$$

$$[G] = \text{sum}(\text{itemScore} \times \text{itemWeight}) \quad \textbf{(2.2)}$$

Those weights were based on an exploratory factor analysis on data collected by the author. No total score for a superior factor was offered, but it is suggested that "Dizziness" factor describes the high levels of cybersickness, while "Difficulty in Focusing" low levels.

Kim et al. (2018) proposed another different subset of 9 SSQ symptoms driven by two latent constructs, "Oculomotor" and "Disorientation", denoting SSQ dimension profiles are different for simulators and VR (Drexler, 2006; Kennedy et al., 2010). 5 symptoms were common with CSQ, but distributed to different factors. Among 12 male and 12 female participants, 6 had prior experience with HMDs and 3 owned a VR device. 4 different treatment conditions of button selection tasks were used as stimuli, employing

2 different selection methods and 2 different button sizes. 96 sessions were conducted with 24 participants under 4 different treatment conditions. Participants used a smartphone based HMD system for the tasks and responded to SSQ items after each treatment condition given in a Latin-square design, with 2 minutes breaks between each condition. An exploratory factor analysis using principal component analysis method with varimax rotation, 11 symptoms were retained with three components. However, the third component was indicated by only "Headache" symptom, which was removed. "Dizziness with eyes open" item was removed from "Disorientation" component due to high covariance value. A CFA (confirmatory factor analysis) verified the fit of the derived model. A simple averaging method was proposed to calculate scores for each component and a total index, in which [H] and [I] values were the sum of the corresponding items in Table 2.1.

Analysis of variance (ANOVA) results revealed that there were significant differences in treatment conditions except for the disorientation score between two button size conditions, which was a static task that did not involve sudden movements. ANOVA results provided evidence for proposed VRSQ is sensitive to different application aspects, in terms of navigation and scene complexity. On the other hand, SSQ scores were found to be sensitive to application aspects for all dimensions.

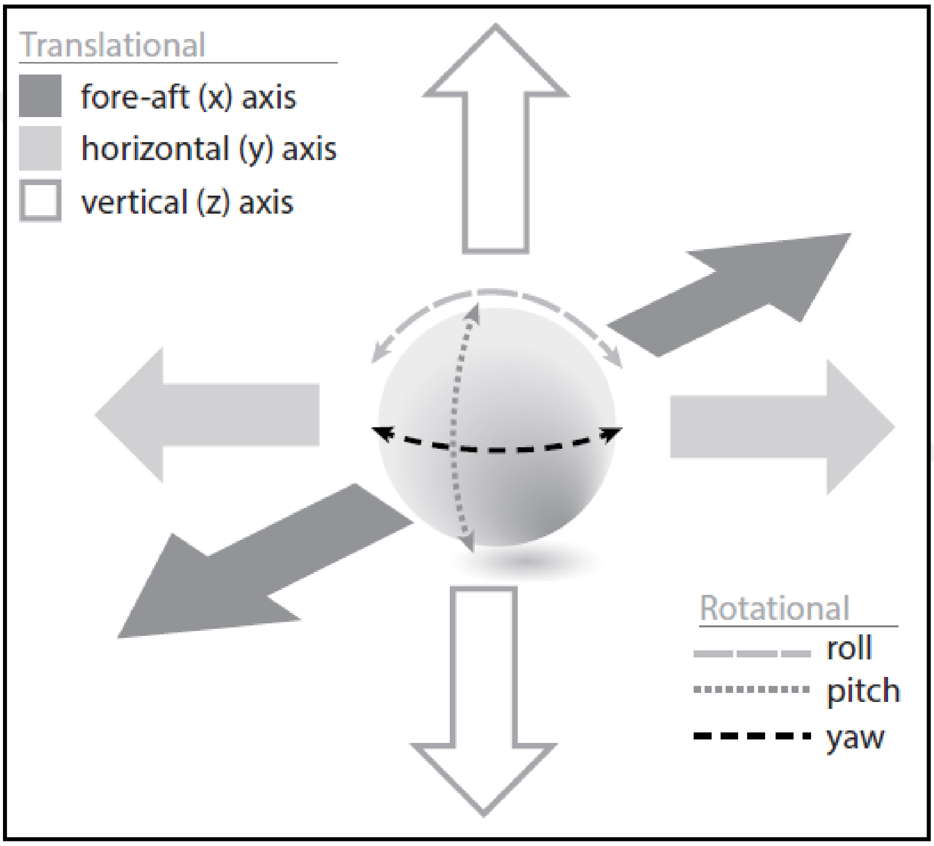
$$\begin{aligned} \text{Oculomotor} &= ([H] / 12) \times 100 \\ \text{Disorientation} &= ([I] / 15) \times 100 \\ \text{Total} &= (\text{Oculomotor score} + \text{Disorientation score}) / 2 \end{aligned} \quad \textbf{(2.3)}$$

2.2 APPLICATION ASPECTS AFFECTING CYBERSICKNESS

SSQ-T scores range from 6 to 160, with an average of upper twenties and "cybersickness appears to increase with more in-depth immersion and forced motion" (Rebenitsch & Owen, 2016). Besides hardware related issues such as field of view (Draper et al., 2001) or limited peripheral vision (Moss & Muth, 2011), application aspects in terms of navigation and scene complexity, rotation, independent visual backgrounds, tracking and position, scene content and realism are known to affect cybersickness (Rebenitsch & Owen, 2016).

Navigation mechanisms in VEs let user to move virtually in translational and rotational axes by generating moving scenes. Translational axes are fore-aft (x), horizontal (y) or vertical (z) and rotational axes are roll, pitch and yaw (Fig.1). Current consumer VR HMD's provide rotational navigation by generating scenes that are opposite to direction of user's actual movement, where actual movement is detected via head tracking.

Figure 2.1: Navigational Axes in Virtual Environments. Adapted from Rebenitsch and Owen (2016).



Exploring a VE with rotational navigation based on head movements is found to cause higher cybersickness compared to hand-controlled rotational navigation with stationary head position (Howarth & Finch, 1999).

On the other hand, translational navigation in VEs cannot be matched to user's actual movement accurately, since the users actually move in a limited space or do not move at all. Locomotion interfaces based on actual movements of the user, such as treadmills and movable tiles (Iwata et al., 2015) are not offered as consumer products yet. Some VEs offer “teleportation” mechanisms for navigation (Jerald, 2015:344). Yet the translational navigation mainly depends on input devices such as game controllers or some sort of automated solutions that are not controlled by the users. Users’ bodies are stationary in the actual space while they are experiencing an illusory self-motion in virtual space, i.e. vection. Vection was associated with cybersickness, in line with sensory mismatch theory (Rebenitsch & Owen, 2016), which is the most common theory of visually induced motion sickness.

So, Lo and Ho (2001) explored the effect of navigation speed in the fore-aft direction and rotation in the yaw axis using a virtual urban scene. 10 male Chinese users reported higher sense of vection and higher SSQ-T scores when translational movement speed in fore-aft axis was increased from 3 m/s to 10 m/s and became steady after 10 m/s up to 59 m/s. SSQ and vection scores were not affected significantly by duration of immersion in VE. Later, So, Ho and Lo (2001b) offered a quantified metric of SV (spatial velocity) for perceived movement in VEs, in order to identify the relationship between navigation speed, scene content, and cybersickness. As a measure of scene complexity, SV was based on the luminance frequency in scene, which could be affected by the movements of users in translational and rotational axes. The cybersickness dose value model (So, 1999), which aimed to predict the severity of cybersickness that might be caused by immersion into a VE, was defined as the integral of SV over time multiplied by display, task, and individual scaling factors.

Dorado and Figueroa (2014) revealed that the cybersickness was lower for ramps compared to stairs due to smoother movement. Although increasing and decreasing the acceleration map real-world movement better, instant stop/start with velocity controlled by joystick tilt caused less motion sickness. Comparison of active (6DoF), active-passive (3DoF) and no-controls conditions resulted in lower cybersickness scores for 3DoF controls that matched the application purpose (Stanney et al., 2002). Serge and Mosh (2015) did not detect a significant difference in motion sickness between an observational task and a navigational task. However, participants who performed the observational task first scored significantly higher in navigational task, compared to participants who performed the navigational task first.

Watanabe and Ujike (2008) observed statistically significant lower SSQ-D scores for a movement in vertical axis alongside for-aft axis, compared to movement only in in horizontal axis, but SSQ-T scores were statistically same for both conditions. Comparison of head/body position based controls and joystick controls yielded better results for head/body position tracking based control (Chen et al., 2013). Rebenitsch and Owen (2016) suggested that the axis of translational movement was not a contributing factor in navigation cybersickness. Instead, the effects were likely to lie with scene content and navigation control. Cybersickness was less likely with smooth navigation and moderate control.

When the movement in rotational axes were explored in terms of cybersickness, SSQ-N scores increased for all pitch, yaw, and roll axis rotations (So & Lo, 1999) but no axis yielded significantly higher scores than the other. Bonata et al. (2009) revealed that combined rotational movement yielded higher cybersickness. Keshavarz and Hecht (2011a, 2011b) had similar findings comparing single axis rotational movement to multiple axis rotations of users on a roller-coaster VE. With a rotating tunnel stimulus, Dennison and D’Zmura (2017) determined that SSQ scores did not differ significantly when participants were seated or standing, but cybersickness increased accordingly for both positions as rotation speed increased. Palmisano, Mursic and Kim (2017) used a rotational stimulus that was inversely-compensated to the same direction of users head movements, which produced higher SSQ scores compared to compensated and uncompensated rotations.

3. DATA AND METHODS

This part of the thesis describes the methods used, making the field study about the psychometric effects of the usage of VE technology.

3.1 PARTICIPANTS

Participants were volunteers from a group of students who had enrolled to courses offered by one of the researchers. A fifteen minute face-to-face briefing was given to candidates in classroom, describing the content of the VE's used in the study and possible side-effects of VR use. They were asked to consider their vulnerability to media such as horror movies and their prior experiences of motion sickness in transportation before agreeing to volunteer for the study. None of the candidates had prior VR experience. For this reason, volunteers were allowed to resign from the study after the first VR session. Of 41 initial participant group, nine declared that they would not like to continue due to discomfort, six left due to horror content and three related due to cybersickness symptoms. The remaining 32 participants (17 females), five with corrected vision were aged from 19 to 25 (M = 21; SD = 1.91), who could be considered as possible young consumers of VR systems interested in cyber-entertainment.

3.2 APPARATUS AND STIMULI

The apparatus was Oculus Rift Consumer Version 1 (CV1) HMD attached to a Windows 10 64-bit personal computer with an i7 processor and R9 90 series graphic card used for running HMD. CV1 has a field of view of 110°. Resolution is 1080 x 1200 per eye with image refreshing rate of 90 Hz. The gamepad Logitech F310 was used as a joystick controller, when necessary.

Seven publicly available VE applications were employed as stimuli which were horror-movie like experiences with suspended horror elements and jump scares. Some examples of suspended horror elements were audio effects such as squeaks or deep screams, blinking lights or representations of supernatural creatures. Jump scares were sudden changes in visual scene with appearance of unnatural objects, persons or creatures. Stimuli had a narrative theme in relation with supernatural events or violence. All experiences were in first person view, using head tracking for rotational movement. Mean experience durations are given in Table 3.1 along with the major navigation properties of applications.

Table 3.1: VE Applications and Experience Durations

Code	Application Name	Translational Movement	Locomotion	Mean Exp. Time (Sec.)	SD
A1	Demonic Guest	None	None	364	41
B	Abe VR	None	None	361	35
C1	Final Rest	Fore axis	Vehicular – Auto	213	20
D	The Night The Carsons Disappeared	None	None	1190	447
E	Affected	3DoF	Joystick controlled walking.	740	335
F	The Visitor	None	None	582	202
G	Insane Decay of Mind	3DoF	Joystick controlled walking.	527	230
C2	Final Rest B	Fore axis	Vehicular – Auto	224	30
A2	Demonic Guest	None	None	370	26

To understand the experience, the participants had, the stimuli are described below: Demonic Guest VR (Mgsstudio, 2016) was used as stimuli A1 and A2 in the first and last sessions. The experience eventuated in a bedroom on a large bed, but users did not see any representations of their body parts as an avatar. On the right side of the room, there was a closed circuit television screen that participant could view other rooms and there was a TV and window on the left. During the experience, users were induced to turn their head to look at the occurring jump scare event via audio and lighting cues. Users watched a demon on a closed circuit monitor, approaching and finally reaching their room. There was no translational movement, but all interaction was based on movements on rotational axes, mainly yaw actions.

ABE VR (Hammerhead VR, 2016) was used as stimulus B on the second session. Experience took place in a medical operating room-like environment. Users saw the representation of their upper bodies and legs, arms and feet strapped to an operating table. A humanistic robot came into the room and started to tell a story about itself, while it was walking beside the operating table and playing with surgical tools. Finally, it chopped out the body parts of the user's avatar. There was no translational movement, but users were forced to rotate their heads to follow the robot, mainly with yaw actions.
Final Rest (Slipgate Studios, 2017) was used as stimuli C1 and C2 in the third and eighth sessions. The experience started as the participants woke up in a hospital room environment, seeing their lower bodies, legs and feet on a hospital bed, unable to move their hands. Then, a dark janitor started to push the bed along the hospital halls, as several jump scare events occured related to some phobias. Users could not control the direction or speed of the translational movement, which was always forwards with smooth turns on the corners. The spatial scene changed, as the hospital bed moved forward and users rotated their heads. The bed was probably working as a "real-world stabilized cue" (Jerald, 2015: 207-208) and reduced the cybersickness. Auditory cues were used to make users turn their heads to see some jump scare events, but those events mostly occured in the field of view of the users. Due to the slow speed of translational movement, the sense of vection was not very strong.

The Night The Carsons Disappeared (Long, 2016), employed as stimulus D at fourth session and let users experience a storyline about Michael Carson and her two daughter's disappearing mysteriously from their home. The experience started with a 30 second walk from the street to a house and the movement was not controlled by the users. Entering the house, users found themselves seated on an armchair, but they could not see their body representation as an avatar. During the rest of the experience, users were directed to make rotational movements via auditory cues to observe objects supernaturally moving around the room. The only jump scare event was a spring toy box and the rest of the experience was mainly based on suspense of horror.

Affected: The Manor (Fallen Planet Studios, n.d.), which was the stimulus E in the fifth session, required a joystick for translational navigation in a haunted mansion. Rotational movements were also required to change the direction of the translational movement, which was the users walk along the center of the field of view. Although the second joystick arm could be used to control the direction of movement, participants were asked not to use this control during the experiment. Routes to four alternative endings were determined by the users, requiring them to make rotational movements in order to explore alternative routes in a maze of halls and galleries where they could experience flashing lights and jump scare events such as bats, floating furniture and supernatural creatures. There was no representation of the user as an avatar.

The Visitor (Long, 2016), used as stimulus F in the sixth session, utilized a dark atmosphere to make users nervous and comfortable, rather than jump scare events. Visual cues such as flickering lights and shadows direct users' rotational movements. Users' bodies or body parts were not represented. The environment was quite similar to stimulus A, in which users lied in a large bed.

Stimulus G employed in the seventh session, was Insane Decay of Mind: The Labyrinth (IV Productions, 2010), had a similar interaction mechanic to stimulus E. In addition, there were puzzles to be solved using gamepad controls. The environment was a school building that had wider and longer corridors compared to the halls in stimulus E. While exploring these corridors for puzzles, users needed to avoid some of the non-player characters. Users' bodies or body parts were not represented. There was a small dot at the center of the viewpoint but it did not work as a "real-world stabilized cue".

3.3 PROCEDURE

The 16 item original English version of SSQ was used for data collection with a four point scale of zero (none), one (slight), two (moderate) and three (severe). The scale was administered immediately after each session. Nine sessions for each participant were spread over four weeks. Participants were discouraged to attend multiple sessions on the same day. If necessary, there were at least 2 hours between sessions and only two sessions were allowed per day. Participants were exposed to the same stimuli at first and last sessions as "no experience" and "maximum experience" conditions, and third and eighth sessions as "low experience" and "higher experience" conditions.

3.4 DATA ANALYSIS

Scales were scored using the methods suggested in related studies as explained under the heading "Psychometric Qualifications of SSQ and its variants".

For each variant of SSQ, a CFA was conducted using Ωnyx structural equation modeling software (von Oertzen et al., 2015) to evaluate the construct validity of measurement models. The root mean square error of approximation (RMSEA), the root mean square residual (SRMR), the comparative fit index (CFI) and the Tucker–Lewis index (TLI) were calculated for each SSQ variant to verify the models' fit to the data collected . Akaike information criterion (AIC) and the Bayes information criterion (BIC) were compared, as the smaller values indicate a better fit of the model (Schreiber et al., 2006).

Discriminant validity was examined through Fornell-Larcker criterion for subdimensions of each scale. For each subdimension, the square root of average variance extracted (AVE) was checked to confirm its being greater than the correlations between the examined dimension and other dimensions of the same scale (Fornell & Larcker, 1981).

Reliability was explored in terms of internal consistency and test-retest reliability. Test-retest reliability was indicated by Pearson correlations between the "no experience" and "maximum experience" conditions; and the "low experience" and "higher experience" conditions, for each scale and their subdimensions.

Internal consistency was indicated as Cronbach's alpha, which was calculated for all 288 cases in 9 sessions, and 224 cases in 7 sessions, excluding the no experience and low experience conditions explained above.

Sensitivity of the scales were explored through a series of ANOVAs for comparison of each stimulus' mean total severity score on each scale (except CSQ which does not offer a total severity score), subdimension scores and proportional subdimension scores. Proportional subdimension scores for FSSQ, VRSQ and CSQ were adjusted using the method suggested by Drexler (2006) for SSQ subdimensions, in which the subdimension score was divided by the sum of all subdimensions. "No experience" and "low experience" conditions were excluded from the analysis.

4. RESULTS

The results of the study will be presented in this part of the thesis. By presenting them, the study results are split into three parts. First of all the validity of the results will be presented, than the reliability and in the end the sensitivity.

4.1 VALIDITY

As an indicator of construct validity, the RMSEA indicator of model fit was not below the acceptable value of less than .06 for neither of the models, closest being 0.95 for CSQ. The SRMR indicator less than .06 shows a model fit for VRSQ and CSQ, 0.037 and 0.038 consecutively. CFI less than 0.95 for VRSQ and CSQ also indicate that these two models fit our data. None of the models fit our data based on TLI less than 0.95 criteria. For these criteria of model fit, VRSQ and CSQ fit to our data according to SRMR and CFI indicators.

AIC and BIC were lowest for the CSQ, indicating its being the best fit of model to the data relative to the other three scales. Model fit indicators are presented in Table 4.1

Table 4.1: Indicators of Model Fit for CFA on SSQ, F-SSQ, VRSQ and CSQ

	SSQ	F-SSQ	CSQ	VRSQ
chi^2	1149.608	612.722	92.694	97.393
Restricted df	97	104	26	26
Df	105	120	36	36
AIC	7128.5	6879	3654	4294
BIC	7270.18	6996	3723	4363.5
RMSEA (<.06)	0.194	0.131	0.095	0.098
SRMR (covariances only) (<.06 or <.08)	0.381	0.19	0.038	0.037
CFI (to independent model) > .95	0.625	0.825	0.951	0.954
TLI (to independent model) > .95	0.594	0.798	0.932	0.936

Exploring the discriminant validity of the sub dimensions for each scale, our results showed that SSQ-O had a high correlation with SSQ-D (r= 0.916, p >.01) which was greater than square root of AVE (0.883) for SSQ-O and AVE for SSQ-D (0.897). All the other sub dimensions were confirmed to fulfill Fornell-Larcker criterion, indicating discriminant validity of the scales. Scale correlations and AVE values for sub dimensions are given in Table 4.2.

Table 4.2: Indicators of Discriminant Validity. Values Given in Bold are √AVE. Italics are Correlations (p<.01)

	AVE	SSQ-N	SSQ-O	SSQ-D
SSQ-N	0.802	**0.896**		
SSQ-O	0.779	*0.855*	**0.883**	
SSQ-D	0.805	*0.840*	*0.916*	**0.897**
		FSSQ-N	FSSQ-O	
FSSQ-N	0.806	**0.898**		
FSSQ-O	0.934	*0.854*	**0.967**	
	AVE	VRSQ-O	VRSQ-D	
VRSQ-O	0.766	**0.875**		
VRSQ-D	0.834	*0.837*	**0.913**	
	AVE	CSQ Dizziness	CSQ Difficulty Focusing	
CSQ Dizziness	0.808	**0.899**		
CSQ Difficulty Focusing	0.765	*0.781*	**0.875**	

4.2 RELIABILITY

Reliability evaluation in terms of internal consistency provided evidence of reliability for all scales, based on Cronbach's alpha indicator. Test-retest reliability changes from insignificant or weak to moderate positive Pearson correlations between different levels of experience.

Table 4.3: Indicators of Reliability

	Internal Consistency		Test-retest Reliability			
	9 sessions	7 sessions	No/Max. Exp.		Low/Higher Exp.	
	Cronbach's α	Cronbach's α	r	Sig. (p)	r	Sig. (p)
SSQ N	.84	.85	.45	.01	.53	.002
SSQ O	.91	.92	.31	.08	.46	.01
SSQ D	.88	.90	.28	.12	.56	.001
SSQ TS	.94	.95	.38	.03	.55	.001
F-SSQ N	.86	.88	.49	.01	.52	.002
F-SSQ O	.91	.93	.35	.053	.45	.01
F-SSQ TS	.94	.95	.39	.03	.55	.001
VRSQ O	.87	.90	.24	.18	.45	.01
VRSQ D	.84	.85	.44	.01	.49	.005
VRSQ Total	.92	.93	.30	.1	.51	.003
CSQ Dizziness	.84	.85	.37	.04	.50	.004
CSQ Diff. in Foc.	.84	.85	.16	.39	.32	.07

Test-Retest reliability indicated by Pearson r value was not significant for SSQ-O, SSQ-D, F-SSQ-O, VRSQ-O, VRSQ Total and CSQ Difficulty in Focusing scores of participants in "no experience" and "maximum experience" conditions ($p>.05$). The scores that significantly correlated between these conditions varied from weak to moderate, as can be followed on Table 4.3 On the contrary, the scores in low/higher experience conditions correlated significantly at a moderate level except the CSQ Difficulty in Focusing scores (r=.32; p>.05) and VRSQ D scores (r=.49; p=.05).

The Cronbach alpha scores obtained through the data acquired in 9 sessions were above .7 for all scales and sub dimensions, indicating an adequate internal consistency (see Table 4.3). When the data from no experience and low experience conditions were discarded, internal reliability increased slightly for all measures, as can be followed on Table 4.3.

4.3 SENSITIVITY

4.3.1 Total Severity Scores

As determined by one-way ANOVAs for each scale's TS (total severity) score, there was a significant effect of the stimuli on mean SSQ TS score ($F(6,217) = 4.91$, $p<.005$), F-SSQ TS score ($F(6,217) = 5.41$, $p<.005$) and VRSQ TS score ($F(6,217) = 4.43$, $p<.005$). According to Tukey post hoc tests, SSQ TS score was significantly higher for stimulus "E" compared to A-2, C-2, F and B. Stimulus "G" SSQ TS score was significantly higher than stimuli F and A. Stimuli "B, C, F and A" SSQ TS scores had closer magnitudes and differences were not statistically significant.

The F-SSQ TS scores were significantly higher for stimulus E compared to A-2, C-2, F and B, same as the SSQ-TS ($p<.05$). But Stimulus "G" F-SSQ TS score was significantly higher than stimuli A, F and C ($p<.05$). The scoring method of F-SSQ TS was sensitive to difference between stimulus G and C while SSQ TS was not.

Exploring the VRSQ TS scores through Tukey post hoc tests, it has been determined that stimulus E score was significantly higher than A and F ($p<.05$). Stimulus G score was significantly higher than stimuli A ($p<.05$). Mean differences of Total Severity scores are given in Table 4.4, where significant differences are denoted in bold characters.

Table 4.4: Mean Differences of Total Severity Scores. Mean Differences Given in Bold are Significant at 0.05 Level

SSQ Total Severity Mean Differences							
	E	G	D	B	C2	F	A2
E		3.74	13.56	**30.62**	**32.37**	**34.83**	**37.87**
G			9.82	26.88	28.63	**31.09**	**34.13**
D				17.06	18.82	21.27	24.31
B					1.75	4.21	7.25
C2						2.45	5.49
F							3.04
SSQ TS M	127.9	124.1	114.3	97.2	95.5	93.0	90.0
SSQ TS SD	59.95	55.80	48.76	21.93	25.82	26.68	19.00

FSSQ Total Severity Mean Differences							
	E	G	D	B	C2	F	A2
E		0.07	0.34	**0.80**	**0.83**	**0.89**	**0.97**
G			0.27	0.74	**0.76**	**0.82**	**0.90**
D				0.46	0.49	0.55	0.63
B					0.03	0.09	0.17
C2						0.06	0.14
F							0.08
FSSQ TS M	3.25	3.19	2.91	2.45	2.42	2.36	2.28
FSSQ TS SD	1.51	1.42	1.24	0.57	0.65	0.70	0.49

VRSQ Total Severity Mean Differences							
	E	G	D	B	C2	F	A2
E		2.14	4.30	14.51	14.61	**16.33**	**17.37**
G			2.16	12.37	12.47	14.19	**15.23**
D				10.21	10.31	12.03	13.07
B					0.10	1.82	2.86
C2						1.72	2.76
F							1.04
VRSQ TS M	57.1	54.9	52.8	42.6	42.4	40.7	39.7
VRSQ TS SD	28.03	26.55	25.07	11.66	14.07	15.08	9.96

4.3.2 Sub Dimension Scores

A series of one-way ANOVAs revealed a significant effect of different stimuli on mean sub dimension scores.

There is a significant effect of different VEs on SSQ-N ($F(6,217) = 4.5$, $p<.005$), SSQ-O ($F(6,217) = 3.83$, $p<.005$) and SSQ-D ($F(6,217) = 5.7$, $p<.005$) scores.

Table 4.5: Sub Dimension Score Magnitudes and Significant Differences Between Scores

	Order of Score Magnitudes	Significant Differences
SSQ N	E>G>D>B>C2>A2>F	E>[C2, A2,F] G>[C2, A2,F]
SSQ O	E>G>D>B>C2>F>A2	E>A2 G>A2
SSQ D	E>G>D>C2>B>F>A2	E>[B,F,C2,A2] G>[F,A2]
VRSQ O	E>G>D>B=C2>F=A2	E>[F2, A2]
VRSQ D	E>G>D>C2>B=F>A2	E>[B,F,A2,C2] G>[B,F,A2,C2]
FSSQ N	E>G>D>B>C2>A2>F	E>[B,C2,A2,F] G>[C2,A2,F]
FSSQ O	G>E>D>C2>B>F>A2	G>A2 E>A2
CSQ Dizziness	E>G>D>C2>F>B>A2	E>[C2,F,B,A2] G>[C2,F,B,A2]
CSQ Diff. Focusing	E>D>G>F>C2>B>A2	E>A2

The significant differences between stimuli mean scores according to Turkey post hoc tests are given in Table 4.5, along with the stimuli ordered by sub dimension scores.

The effect on SSQ score was due to significant differences of Stimuli E and G scores being higher than other stimuli. On SSQ-N, E and G scores differentiated significantly from three other stimuli. SSQ-O score distinguished both E and G from A. SSQ-D score of stimuli E was significantly higher than other four, while stimuli G score was significantly higher than other two. Results suggested that SSQ-N and SSQ-D scores were sensitive to differences between application aspects.

We observed a significant effect of different VEs on F-SSQ-N ($F(6,217) = 6.39$, $p<.005$) and F-SSQ-O ($F(6,217) = 4.04$, $p<.005$). F-SSQ-N provided similar scores with SSQ-N in terms of distinguishing software, with an addition that detecting a significant difference between E and B, which was not detected by SSQ-N. FSSQ-O and SSQ-O yielded same results in terms sensitivity. FSSQ had more items per sub dimension that it was likely to provide higher sensitivity.

VRSQ-D ($F(6,217) = 5.42$, $p<.005$) and VRSQ-O ($F(6,217) = 3.28$, $p<.005$) were also affected by different stimuli. VRSQ-D scores showed that both E and G scores were significantly higher than four other stimuli. For VRSQ-O, only stimulus E score was found to be higher than F and A. The difference of E from F was not detected by SSQ-O and FSSQ-O, but they provided a significant difference between G and A, which could not be detected by VRSQ-O.

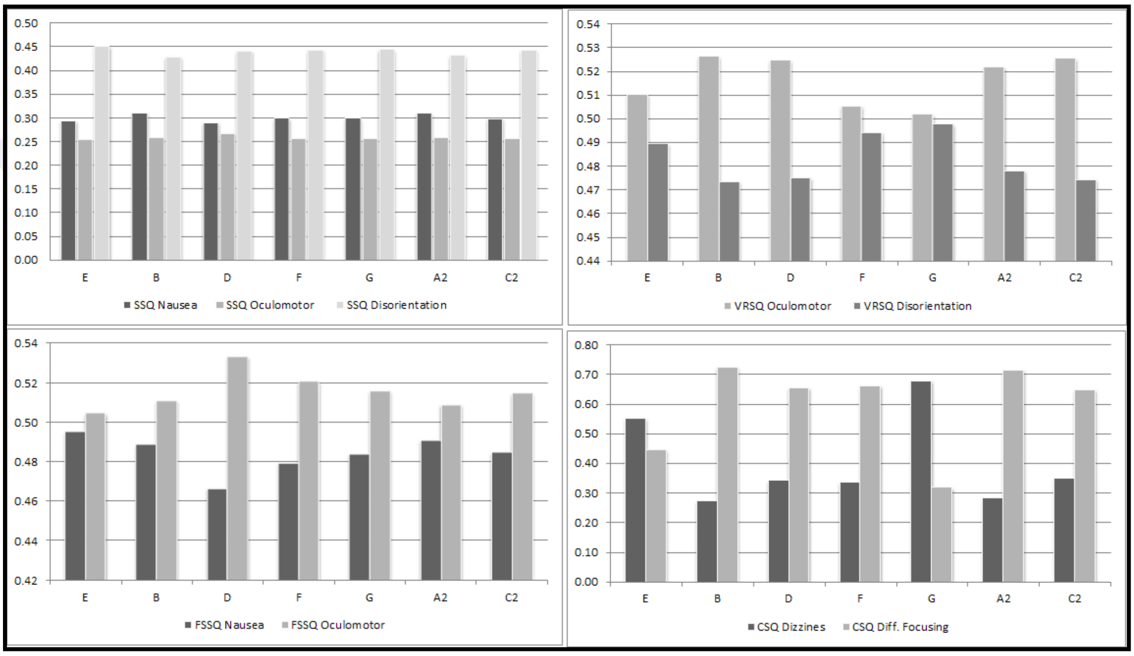
There was a significant effect of different VEs on CSQ Dizziness ($F(6,217) = 8.23$, $p<.01$) and Difficulty Focusing ($F(6,217) = 3.19$, $p<.005$) dimensions. CSQ Dizziness score yielded the same result with VRSQ-D. Difficulty focusing score was only significantly different between two stimuli.

4.3.3 Scale Profiles

Running one-way ANOVA's on each sub dimension proportional score, a significant effect of the stimuli only on CSQ Dizziness proportional score ($F(6,217) = 11.37$, $p<.005$) were determined.

As shown on Figure 4.1, SSQ sub dimension profiles for each stimuli have a D>N>O pattern, which is different from O>N>D findings in previous studies. F-SSQ profiles have a pattern of O>N, VRSQ profiles are observed as O>D. For CSQ, Dizziness is greater than Difficulty Focusing for stimuli E and G, other stimuli are vice versa. As Stone III (2017) suggested that Dizziness factor represented higher levels of cybersickness, this results matched with the TS scores in other scales.

Figure 4.1: Scale Profiles Based on Proportional Sub Dimension Scores



5. DISCUSSION AND CONCLUSION

5.1 DISCUSSION

Results based on CFA did not suggest evidence of construct validity for SSQ and FSSQ in evaluation of cybersickness experienced using publicly available VE software engaged through a consumer HMD. On the other hand, there was evidence of construct validity for VRSQ and CSQ. CSQ had been developed based on a dataset collected through the publicly available VE software, similar to the dataset, used in the study, while VRSQ had been developed using a dataset collected through a custom target selection application. For this reason, CSQ might have showed a slightly better fit to our data, compared to VRSQ. Although VRSQ and CSQ have five symptoms in common among their nine items, their reduced item structure represented the dimensions of cybersickness more accurately.

The high correlations within the scales' sub dimensions imply multicollinearity. As the scoring method of SSQ employs several symptoms in multiple dimensions, that was not unexpected for SSQ sub dimensions. Based on Fornell-Larcker criterion, it was verified that SSQ-O and SSQ-D dimensions did not provide discriminant validity for evaluation of consumer VEs. The evidence for discriminant validity of other constructs, suggesting that cybersickness was more likely to be a bi-dimensional construct, was provided.

The evidence on reliability of SSQ and its variants were also provided. However, in terms of test-retest reliability, the self-reported symptoms of cybersickness did not correlate sufficiently in repeated experiments. The reliability of scales were probably affected by the experience level of users. The self-reported symptoms of cybersickness changed as users engaged more with different VEs. This might have been due to the users' adaptation to the VR. On the other hand, the weaker and insignificant correlation of very first engagement with the repeated measurement might be due to the self-induced motion sickness (Almeida et al., 2017), that occurs when the VR users are informed about the side effects of HMD use before they experience it (Young et .al, 2007). However, the moderate correlations between low and higher experience conditions also suggest that cybersickness measures are not strongly reliable when the users' levels of experience vary. Still, reliability by means of internal consistency is adequate when lowest experience cases are included in analysis.

When the sensitivity of TS (total severity) scores are inspected, VRSQ TS scoring method is less capable of distinguishing the level of cybersickness based on the application aspects, compared to SSQ and FSSQ, since VRSQ has fewer items. Although CSQ does not provide a total severity measure, the CSQ profiles of stimuli that cause a higher level of cybersickness are different from the profiles of other stimuli. The profile based on proportional CSQ scores yields a higher Dizziness score when stimulus triggers vection, which is known to be an application aspect that causes motion sickness. CSQ proportional Dizziness score being higher than Difficulty Focusing score can be used as an indicator of higher levels of cybersickness, as suggested by its developer.

Since there was not a significant effect of stimuli on mean proportional sub dimension scores except CSQ Dizziness, these scores were not found to be sensitive to the effect of application aspects on cybersickness.

When the sub dimension scores were evaluated, VRSQ-D and CSQ Dizziness scores were found to be highly sensitive to application aspects, compared to SSQ-D. Absence of Nausea related items; burping, stomach awareness, increases salivation and sweating; did not decrease the sensitivity of sub dimensions in CSQ and VRSQ and it was possible to compare different VEs without the nausea dimension. However, it should be noted that the SSQ-N scores were also highly sensitive to differences between VEs. Besides the SSQ-N Nausea symptom is still a part of CSQ Dizziness and SSQ-N General Discomfort symptom is included in VRSQ-D.

Based on the literature on “Application Aspects Affecting Cybersickness”, stimuli E, G and C were suspected to trigger higher levels of cybersickness, as they allow translational navigation as well as rotational navigation, and translational navigation which yields vection. Stimulus C was expected to cause less cybersickness compared to E and G, since the translational movement was only in fore-axis with a constant speed, not controlled by the user. Stimuli A, B, D and F only allowed rotational navigation, where users were located in virtual rooms in which only certain objects moved. Usually, users were stimulated by directional audio to rotate their heads to a direction to let them see a moving object. The longer session durations were likely to cause higher levels of cybersickness in these type of VEs.

There was the evidence of sensitivity to application aspects, but the results of the stimuli C, E and G, triggering the highest level of cybersickness, based on vection due to discordant translational movement were not as expected. Although the highest scores for all measures were on stimuli E and G, stimuli B and D provided higher scores than C for most of the measures. As applications B and D require a lot of rotational movements to follow the objects in the scene, this may have also caused cybersickness. The slow-pace automated translational movement in stimuli C did cause a lower level cybersickness than we expected.

5.2 CONCLUSION

Our results suggested that CSQ and VRSQ, which were specifically designed for measuring cybersickness, had better psychometric qualities for assessing HMD VR applications, when they were compared to SSQ and F-SSQ, which were tools that were intended to measure simulator sickness. The evidence for validity of CSQ and VRSQ was provided, as cybersickness measures, while SSQ and F-SSQ could not be validated psychometrically. The results provided evidence for reliability of all measures. VRSQ and CSQ were highly sensitive to differences between the application aspects of evaluated VEs, although they investigate fewer symptoms than simulator sickness scales.

However, since the psychometric qualities of CSQ and VRSQ are quite similar, trying to decide which one is superior to the other in evaluation of cybersickness in consumer VEs becomes difficult.

When the symptoms employed in these scales are investigated, there were similarities as well as inconsistencies.

The three symptoms that were mainly related to digestive system; Increased Salivation, Burping and Stomach Awareness; were excluded both in CSQ and VRSQ, but CSQ still incorporated the Nausea symptom as an indicator of cybersickness, which is also related to the digestive system. Both scales exclude the Sweating symptom. As Sweating can be related to physical effort or some other psychological state such as fear or excitement, its absence enhances the face validity of the scales. Eye Strain, Difficulty in Focusing and Blurred Vision are used in both scales as ocular symptoms of cybersickness. However, VRSQ evaluates the General Discomfort and Fatigue items in the same dimension with two of those ocular system symptoms, while it uses Blurred Vision as an indicator of Disorientation. Other two common items, Dizzy (eyes closed) and Vertigo are symptoms mainly related to vestibular system. The Headache and Fullness of Head symptoms are effects that can be related to nervous system. While CSQ operates Fullness of Head among with symptoms related with ocular system, VRSQ uses it along with items related to vestibular system. In both scales, Headache is evaluated among the vestibular system symptoms.

We should not disregard the fact that CSQ was developed through an item-response theory approach, while VRSQ developers followed a factor analysis based method. VRSQ was based on a sample of 16 different users, while CSQ was developed on data collected from 202 different participants. The stimuli in the experiments of VRSQ was limited to four different selection tasks with mobile HMDs, as CSQ participants evaluated one of the two consumer VEs that had different navigation mechanisms. VRSQ uses a simpler scoring system compared to CSQ. Considering the limitations in their development process, neither CSQ nor VRSQ have evolved in ideal conditions that represent the stimuli and participants of consumer VEs.

This study employed a broader range of consumer VE applications with different methods of interaction and navigation, compared to both VRSQ and CSQ studies. On the other hand the sample was limited to 32 individuals. The sample size cannot be considered as a representation of the population of VR consumers.

These considerations prevented us from offering a new scale based on SSQ items. Although the results also supported CSQ and VRSQ for their assumption that the symptoms in digestive system were not related with cybersickness, it is suggested further research using SSQ items, to cover more wider user populations and different stimuli that represent broader application aspects of consumer VEs. For this reason this thesis should be used as supplementary research in this field and open up new research ideas for further researchers.

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