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Correlating reaction time and nausea measures with traditional measures of cybersickness ☆

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ABSTRACT

We provoked cybersickness in participants by immersing them in one of two virtual roller coaster rides using a head-mounted display. As simulation technology is often used in training, our main intention was to examine the effect of the experience on their cognitive function. Participant reaction times before and after the experience were measured by averaging their response time to a visual stimulus over a number of trials. We measured a significant reduction in response time before and after the virtual experience. We also examined the changing state of nausea experienced by participants using some simple nausea measures. These included a repeated nausea rating recorded by participants at two-minute intervals. At the completion of the experience, we averaged these ratings to create a standard nausea score. As participants could decide to stop the experience at any time, we also recorded the voluntary duration of the experience. We correlated our measures with two traditional simulator sickness measures, namely the Motion Sickness Susceptibility Questionnaire (MSSQ) and Motion Sickness Assessment Questionnaire (MSAQ). The standard nausea score provided a simple measure of nausea that could be collected at regular intervals with minimal interference to the immersive experience, and was significantly correlated with both the MSSQ and MSAQ scores.

1. Introduction

The technology associated with Virtual Reality [1] has been under constant development since Ivan Sutherland first described many of the concepts surrounding his Ultimate Display [2,3]. Over the intervening years, much progress has been made in developing the various technologies required for generating seamless, natural interaction in virtual worlds [4] and to meet some of the visionary goals described for Virtual Reality [5]. A broad application of this technology remains the domain of training and education. However, there has been a recent growth in demand for affordable immersive environments, particularly head-mounted displays (HMDs). For example, cost effective devices such as the Oculus Rift HMD are evolving to meet a growing consumer demand [6]. Affordable display technologies associated with PlayStation VR [7], HTC Vive [8], and Google [9] have also emerged to try and meet the expected demand for immersive game interfaces, and for social interaction with applications such as Facebook [10].

However, one problem still experienced in immersive simulations is the uncomfortable side effects associated with conditions such as cybersickness [1]. Previous research has shown that participants can experience a range of unpleasant physical responses when subject to virtual environments [11–13]. These generally minor, short-term health risks [14] remain a potential issue for the broader adoption of these technologies. While for most people the effects are minor, some estimates for the percentage of the population affected during exposure are as high as 60–80% [11,15].

Typical symptoms of cybersickness include nausea, eyestrain and dizziness [16]. Motion sickness and simulator sickness share many symptoms with cybersickness. This includes apathy, sleepiness, disorientation, fatigue, vomiting, and general discomfort, which are typical of the symptoms trainees may experience in simulators [16]. Furthermore, post-training effects can impact on individuals, with effects such as drowsiness or postural instability occurring immediately after training or even many hours later [17]. In this study we focus on symptoms of nausea and changes in participant reaction time.

Symptoms are known to vary greatly between individuals, and depend on the technologies being used, the design of the environment, and the tasks users are performing in the environment [17]. There is an evident relationship between the symptoms of motion sickness, simulator sickness and cybersickness [12]. Although, in

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each case these symptoms are induced by exposure to slightly different situations, and different clusters of symptoms seem to differentiate the three conditions [12]. Motion sickness is the unpleasant feeling, accompanied by nausea, dizziness, and vomiting, that may occur when people travel in moving vehicles. Astronauts can also experience a related form of motion sickness; called 'space adaptation syndrome', that occurs in exposure to zero gravity conditions [18]. Simulator sickness occurs in simulators with moving platforms when discrepancies between the perceived and actual motion occur [19]. Cybersickness affects stationary users who experience the sensation of moving in the virtual scene [18]. In our study, we provoke this condition by immersing stationary users in a virtual roller coaster ride using a HMD.

Both subjective [11,12,18,20–29] and objective [13,30–36] approaches have been applied to try and understand the multiple factors that impact on these conditions, the types of symptoms, as well as the susceptibility of individuals to the various symptoms. Historically, one of the earliest survey instruments for assessing motion sickness [37] was known as the Pensacola Motion Sickness Questionnaire [38]. It was based on 27 previously identified issues [22]. This early work led to the development of the Pensacola Diagnostic Index [28], calculated by summing an individual's ratings on various scales related to the symptoms of dizziness, headache, warmth, sweating, drowsiness, salivation, and nausea.

As simulation technology developed, the Pensacola Motion Sickness Questionnaire was modified several times until, after a major study analyzing the symptoms relevant to simulator sickness, an alternative 16-item Simulator Sickness Questionnaire (SSQ) [23,25,26] was proposed. These 16 symptoms were found to cluster into three categories; oculomotor, disorientation, and nausea. The oculomotor cluster included eyestrain, difficulty focusing, blurred vision, and headache. The disorientation cluster symptom included dizziness and vertigo. The nausea cluster included stomach awareness, increased salivation, and burping. While correlated with the previous Pensacola Motion Sickness Questionnaire, this new questionnaire also allowed the identification of multivariate measures related to the oculomotor, disorientation, and nausea dimensions.

One dimension of cybersickness that was not directly assessed by the Simulator Sickness Questionnaire was the sopite syndrome [38]. This dimension includes symptoms such as drowsiness, yawning, and disengagement from the environment [39]. To address this issue, a further multivariate questionnaire was developed to measure the symptoms associated with the four subscales of gastrointestinal, central, peripheral, and these sopite-related symptoms [20]. Because the Motion Sickness Assessment Questionnaire (MSAQ) [20] is one of the more commonly used multivariate questionnaires for recording cybersickness symptoms, we have also incorporated this into our own study.

In terms of gauging individual susceptibility to symptoms, the Motion Sickness Susceptibility Questionnaire (MSSQ) is one of the traditional approaches [20]. It relates a user's experience with motion sickness, both as a child and adult, to predict the likelihood of a person also suffering from cybersickness [18]. The original MSSQ [26] is the most widely used and validated approach to assessing an individual's susceptibility to such conditions [18]. This original MSSQ was updated in 1998 to simplify the rating and scoring mechanisms [18]. This newer validated questionnaire captures the individual's travel experiences and their relation to any nausea or vomiting. It records experiences both prior to the age of 12, and in the individual's previous 10 years in a variety of vehicles such as cars, buses, trains, aircraft, and boats, as well as fairground and playground rides. A susceptibility rating is calculated on the basis of quantified Likert rankings regarding the severity of experiences and the frequency of occurrences. Because of the prominent historical use of this susceptibility questionnaire, we decided to include it in our own study.

We are particularly interested in studying the onset of nausea in relation to cybersickness caused by immersive experiences in HMDs. To avoid too great an impact on the immersion of the experience, we are trying to gather nausea ratings that only require minimal feedback from participants. In this experiment we consider two simple measures; the duration of voluntary exposure (0–14 min) and a standard nausea score (0–10) collected over the period of the virtual experience. The standard nausea score is intended to capture the amount of nausea the participant would experience over the full of the ride. It is an average of the participants 7 nausea ratings taken at each 2-min period of the ride. Where a participant has decided to leave the ride early, it uses the participants' final nausea rating for the calculation. Our intention is to correlate these simple nausea measures with more traditional and well-validated simulator sickness instruments, namely the revised MSSQ [18] and the MSAQ [20]. Of particular interest is any correlation between the MSAQ-Gastrointestinal subscale and our nausea measures.

As these types of virtual experiences are often proposed for training situations, we also wished to measure any effect cybersickness might have on cognitive function. In this study we measure changes in user reaction time after exposure to the virtual experience. Again we wanted to try and correlate this measure with the MSSQ [18] and MSAQ [20] scores. In this case we were particularly interested in any correlation between the MSAQ-Central subscale and any changes detected in participant reaction time.

In summary there are a number of questions we addressed in this study:

1. Are there any indications of impaired reaction times [40] that result from cybersickness, and how does this measure correlate with the MSAQ scores [20]?
2. Do our nausea measures, voluntary exposure time and standard nausea score, correlate with the cybersickness symptoms measured with the traditional MSAQ scores [20]?
3. How well does the MSSQ score [18] correlate with our simple nausea measures and changes in participant reaction time?

2. Method

An experiment was conducted on 24 participants aged from 18 to 32, with an average age of 22.5 years (SD = 3.5). Overall, 79.2% (19/24) of participants were male and 20.8% (5/24) were female. We also collected information about participant exposure to virtual environments in the form of video games. Twenty-five percent (6/24) of participants played 0–5 h of video games per week, 25% (6/24) played 5–10 h of games per week, while 50% (12/24) played more than 10 h of games per week. The participants were mostly undergraduate students studying Information Technology. Participants were only included if they had normal vision and vestibular function, and were not suffering from symptoms of cold or flu. Participants were also excluded if they were pregnant or were known to suffer from conditions that might be aggravated by wearing an immersive HMD, such as vertigo, claustrophobia, or epilepsy.

Approval for the study was obtained from the Newcastle University Human Research Ethics Committee (Approval number: H-2014-0266). The Ethics Consent Form explained that the aim of the experiment was to investigate nausea associated with a roller coaster ride simulated in a HMD, and advised participants that they were free to withdraw from the study at any time.

To account for potential stimulus specific effects, two different virtual roller coasters were used in the experiment (see Fig. 1).