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Profiling subjective symptoms and autonomic changes associated with cybersickness

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ABSTRACT

Our aim was to expand knowledge of cybersickness – a subtype of motion sickness provoked by immersion into a moving computer-generated virtual reality. Fourteen healthy subjects experienced a 15-min rollercoaster ride presented via a head-mounted display (Oculus Rift), for 3 consecutive days. Heart rate, respiration, finger and forehead skin conductance were measured during the experiment; this was complemented by a subjective nausea rating during the ride and by Motion Sickness Assessment Questionnaire before, immediately after and then 1, 2 and 3 h post-ride. Physiological measurements were analysed in three dimensions: ride time, association with subjective nausea rating and experimental day. Forehead, and to a lesser extent finger phasic skin conductance activity showed a correlation with the reported nausea ratings, while alteration in other measured parameters were mostly related to autonomic arousal during the virtual ride onset. A significant habituation was observed in subjective symptom scores and in the duration of tolerated provocation. The latter increased from 7.0 ± 1.3 min on the first day to 12.0 ± 2.5 min on the third day ($p < 0.05$); this was associated with a reduced slope of nausea rise from 1.3 ± 0.3 units/min on the first to 0.7 ± 0.1 units/min on the third day ($p < 0.01$). Furthermore, habituation with repetitive exposure was also determined in the total symptom score post-ride: it fell from 1.6 ± 0.1 on the first day to 1.2 ± 0.1 on the third ($p < 0.001$). We conclude that phasic changes of skin conductance on the forehead could be used to objectively quantify nausea; and that repetitive exposure to provocative VR content results in habituation.

1. Introduction

It is currently well accepted that motion sickness (MS, or kinetosis) develops when conflicting signals are received from the spatial orientation senses - vestibular, visual and proprioceptive. Such sensory conflict can be initiated within a single sensory system such as canal-otolith interaction during Coriolis cross-coupling, or between two or more sensory systems such as visual/vestibular/proprioceptive interaction when on a boat in rough seas (Reason and Brand, 1975). MS could be provoked by a broad variety of causes, and it is according to these causes and also according to the predominant sensory influence that MS has been historically classified as sea-, air- or carsickness; simulator sickness; space sickness; and visually-induced motion sickness. The key role of the vestibular system in the pathogenesis of MS is evident from the fact that subjects with bilateral vestibular deficit are immune not only to vestibular but also to visual provocations (De Wit, 1953; Johnson et al., 1999; Money, 1970).

Cybersickness refers to MS induced by the immersion of stationary users in moving scenes using computer-generated virtual reality (VR), especially with the assistance of more immersive interfaces such as VR head-mounted displays. Although such VR devices have been around for decades (Jerald, 2016; Sutherland, 1968), due to their high cost and limited application there has been little research conducted in understanding the biological impact of these devices. With the increasing trend in the application of VR and computer games in everyday life, it becomes evident that cybersickness is the main obstacle in broad adoption and commercial expansion of VR technology, especially in fields like education and training. There are numerous factors of VR technology that could be responsible for these alterations; generally they could be classified into two categories: hardware-dependent (e.g. a lag between head move and visual field move, monitor flicker, disaccord between vergence and accommodation) and content-dependent (e.g. vigorous linear and/or angular accelerations) (Jerald, 2016). Information regarding potential effects of cybersickness on human physiology is limited, and expanding this area was our primary aim for this work.

Abbreviations: HR, heart rate; MS, motions sickness; MSAQ, motion sickness susceptibility questionnaire; MSAQ, motion sickness assessment questionnaire; VR, virtual reality.

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The most common and known symptoms of MS are cold sweating, nausea and vomiting, and facial pallor (Money, 1970; Reason and Brand, 1975); previous studies however revealed that the list of MS symptoms is substantially longer. It is now accepted in the field that all MS is a multidimensional syndrome, and that all its symptoms could be split into four clusters: gastrointestinal (stomach awareness, nausea, vomiting); central (fainting, light headiness, disorientation, dizziness, sensation of spinning); peripheral (sweating, feeling hot) and sopite (annoyance, drowsiness, tiredness, uneasiness) (Gianaros et al., 2001). A common established psychometric tool for their assessment is Motion Sickness Assessment Questionnaire (MSAQ) (Gianaros et al., 2001). It appears that there are some differences in symptom profile between the subtypes of MS: for example, Kennedy and colleagues reported that some symptoms of simulator sickness are less severe and less common compared to "classic" MS (Kennedy et al., 1993). To the best of our knowledge, symptom profiling of cybersickness has never been performed, and this was one of our aims; this was complemented by an attempt to establish objective biological markers that could be used for assessing and monitoring nausea during cybersickness. Here, we suggested that similar to vestibular provocations, the most sensitive measure would be phasic changes of skin conductance on the forehead (Golding, 1992; Golding and Stott, 1997). Lastly, we aimed to determine whether repetitive exposure to the provocative VR content would result in habituation (i.e. reduction of objective signs and subjective symptoms of cybersickness following repetitive exposure to VR) like it occurs during repetitive vestibular provocations (e.g. (Bagshaw and Stott, 1985; Lucertini and Lugli, 2004)). To this end, we exposed our volunteers for 3 consecutive days to a 15-min virtual ride on a roller coaster using the Oculus Rift, a common consumer VR product; we concurrently recorded ECG, respiratory rate and phasic and tonic changes in skin conductance in fingers and on the forehead, and assessed both immediate and delayed symptoms of cybersickness.

2. Methods

2.1. Participants and general experiment outline

The study was conducted in 14 healthy volunteers (average age 29 ± 6.1 range 18–37 years old) of both genders (8 female and 6 males), with the approval of the Human Research Ethics Committee of Newcastle University. In this study each participant was asked to undergo a simulated roller coaster ride for three consecutive days. On the first day, on arrival to the lab (air conditioned room kept at 21–22 °C), subjects rested for 10 min, signed an informed consent form and completed the and revised motion sickness susceptibility questionnaire (MSSQ) (Golding, 1998); this was complemented by a question regarding previous experience with VR. After fitting the head-mounted virtual display (Oculus Rift DK1, Oculus VR, USA), we obtained a 5-min baseline recording of heart rate, respiration rate, finger skin conductance and forehead skin conductance. During this period a static stereoscopic neutral image was displayed on the screen. Subsequently, the rollercoaster simulation ride (Helix, Archivision, NL) was activated and lasted for a maximum of 15 min. However, the participants were able to terminate the ride whenever they felt uncomfortable to proceed. During the ride subjects were asked to rate their level of motion sickness every minute on the scale from zero (no effect) to 10 (severe MS - just about to vomit). After the ride, subjects completed the Motion Sickness Assessment Questionnaire (MSAQ) (Gianaros et al., 2001); this assessment was also repeated 1, 2 and 3 h post-ride to rate the regress of the symptoms. The symptoms were categorized into four clusters: gastrointestinal (nausea, feeling sick in the stomach, feeling queasy, about to vomit) central (faint-like, light headiness, disoriented, dizzy and spinning), peripheral (sweaty, hot, clammy, cold sweat, temperature discomfort) and sopite (annoyed, drowsy, tired, uneasy). When answering each question of the MSAQ, the participant assigns a value from a range of 1 "not at all" to 9 "severe". These ratings are then summed for each group of related questions and used in a formula for each subscale, where Rating = (Sum of each subclass symptom rating) / [(Number of the questions related to the corresponding subclass) × 9]. The overall MSAQ motion sickness score is calculated as: Score = (Sum of all items / [(Number of all questions) × 9]. On each of the experimental days, subjects also rated the delayed symptoms 1 h, 2 h and 3 h after the termination of virtual ride.

2.2. Data collection and analysis

ECG and respiration was measured using 3-lead electrodes and respiratory belt respectively. The finger and forehead skin conductance levels (SCL) were measured using constant voltage UFI Model 2701 BioDerm Skin Conductance Meter (UFI, Morro Bay, USA). For both SCL locations, we used 8 mm diameter silver/silver chloride electrodes filled with conductive gel (UFI, Morro Bay, USA). The finger electrodes were positioned on the palmar surface of middle phalanxes of the index and the middle fingers of non-dominant hand. The forehead electrodes were placed on the right and left sides of the forehead 1 cm bellow the hairline, at about the lateral corners of the eyes. All the sensors were connected to PowerLab-8s data acquisition system and a computer running Chart 8.0 (ADInstruments, Sydney, Australia). Sampling rate was 1 kHz for ECG and 100 Hz for respiratory and skin conductance signals. Heart rate (HR) and respiratory rate were computed online using R-R ECG intervals and the peaks of respiratory signal, respectively. To compute the phasic component of the skin conductance signal we applied a high pass filter with a cut-off frequency of 0.05 Hz (Golding, 1992; Golding and Stott, 1997). Amplitude Root Mean Square (RMS) and the frequency of SCL transients in the phasic component was calculated using LabChart software.

For the purpose of statistical analysis, all signals were averaged at 1-min intervals. Statistical analyses were performed using Prism v.6.1 (GraphPad, USA). One-way ANOVAs for repeated measures were performed to determine the effects of time on nausea rating, the effect of repetitive provocation on the ride duration and the effect of repetitive exposure on the slope of nausea rating vs. time relationship. The slope was determined by a linear fitting procedure according to the formula (Nausea rating = m × Time + c), where m is a slope. Spearman's correlation was used to assess relations between the MSSQ score and ride duration. We performed two types of analysis of physiological parameters: i) dependence of measured variables on riding time; and ii) dependence of measured variables on nausea rating; we also determined whether habituation of MS symptoms occurred during the second and the third provocation. As all participants terminated their ride at different times, we could not perform overall averaging of their data traces for the first type of analysis; instead, similar to (Golding, 1992), we selected for comparison three points: baseline (before the ride), the first minute of the ride, and the last minute of the ride (i.e. when the nausea level was the highest). For the second type of analysis, data were split into "no nausea" (rating 0), "light nausea" (rating 1–3), "moderate nausea" (rating 4–6) and "strong nausea" (rating > 6) bins. Two-way 3 × 3 factorial design ANOVAs for repeated measures were then applied, with the two factors being the recording time (baseline, first and last min of the ride) and the day (1st, 2nd, 3rd) for the first type of analysis; and nausea rating and the day for the second type. Follow-up analyses were conducted using Student's *t*-tests, with a Bonferroni correction for multiple comparisons for each outcome variable separately. Data are presented as means ± standard error of the mean (SEM). Statistical significance was set at $p < 0.05$.

3. Results

3.1. Effects of virtual ride on nausea levels

All participants reported vection and some level of nausea during the ride. Only one of the participants managed to complete the 15 min ride