가상현실에서 사이버멀미의 생리적 요인

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Physiological Components of Cybersickness in a Virtual Reality

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Abstract

We investigated the physiological patterns of cybersickness in a Virtual Reality (VR). Subjects were exposed to the VR for 9.5 min, and required to detect specific virtual objects. Sixteen electrophysiological signals were recorded before, during, and after the virtual navigation. Five questionnaires on the VR experience were acquired from 61 healthy subjects. During the virtual navigation, subjects with the high cybersickness susceptibility showed significant physiological changes, which included increased gastric tachyarrhythmia, eyeblink frequency, and EEG delta wave and decreased EEG beta wave. These results suggest that cybersickness may induce or accompany the changes in central nervous system and autonomic nervous system. Also, these results suggest that there may be increased sympathetic activation in autonomic drive for cybersickness.

Keywords: Virtual reality, Cybersickness, EEG, Autonomic nervous system

1. Introduction

Although Virtual Reality (VR) technology is very promising, there exists a potential threat to the ultimate usability of VR. Many

users experience discomfort during and sometimes after a session in a virtual environment (Cobb, Nichols, Ramsey, & Wilson, 1999; Regan & Price, 1994). The term cybersickness has been used to describe the form of motion sickness experienced in virtual environment. In a typical virtual environment, users often view moving scenes while they remain physically stationary. The symptoms of cybersickness, such as nausea and dizziness, are similar to some of those reported during motion sickness, simulator sickness and space sickness. Although the symptoms may be similar, their geneses are somewhat different from each other. Generally, cybersickness is not induced by actual motion, but changes in the visual world.

Cybersickness triggered by exposure to moving visual environments can be derived from sensory conflict, because these situations are accompanied by vestibular cues, which report that the body is stationary and controversial visual cues that the body is moving. People do not suffer from cybersickness in a virtual environment if they close their eyes, whereas closing the eyes is no protection against conventional motion sickness.

The most common measures of cybersickness are questionnaires and postural tests. Physiological measures would offer objective measures of cybersickness if found to be both reliable and valid. Prior research, for example, has shown that motion sickness induced symptom is associated with increased sympathetic cardiac activity (Cowings, Suter, Toscano, Kamiya, & Naifeh, 1986), increased skin conductance (Miller, Sharkey, Graham, & McCauley, 1993), and increased gastric tachyarrhythmia (Hu, Grant, Stern, & Koch, 1991). Changes in the activity of the human cerebral cortex have also been detected during motion sickness using EEG recording (Chelen, Kabrisky, & Rosers, 1993).

Major purpose of this paper is to predict cybersickness susceptibility by analysis of physiological responses to cybersickness. We provided subject with the virtual navigation for 9.5 minutes, recorded physiological measurements before, during, after navigation in the VR, and examined self-report for evaluating the virtual navigation. We used the physiological variables such as heart period, respiratory sinus arrhythmia, respiration rate, eyeblink rate, fingertip pulse volume, fingertip temperature, skin conductance, gastric tachyarrhythmia, and EEG power spectrum because they have been used in previous studies of motion sickness, and represent different aspects of the physiological changes.

2. Method

Participants: Healthy sixty-one (31 males and 30 females) undergraduate students participated in the study. The mean age was 23.08 years (SD = 2.05, aged 19-27 years). None of the subjects had experienced VR before.

VR system: The VR system used in this study was the 3D Visual and Auditory Environment Generator (VAEG), which had three channels with CRT (cathode ray tube) image display. The systems were implemented on a Silicon Graphics Onyx Reality Engine 2 Workstation with full color, constant 30 frames per second, and

high-resolution (3840×1024). The field of view of screen was approximately 150 horizontally by 45 vertically.

Apparatus: The polygraph was composed of couplers for electrocardiogram (ECG 100), electrooculogram (EOG 100), skin conductance (GSR 100), photoplethysmogram (PPG 100), skin temperature (SKT 100), Electrogastrogram (EGG 100), Respiration pneumogram (RSP 100) and 9 electroencephalograms (EEG 100) with an MP 100 workstation with 16-bit A/D conversion. Data were gathered with a sampling rate of 400 Hz. Eletroencephalogram (EEG) were recorded from the 9 scalp loci at F3, F4, Cz, T3, T4, P3, P4, O1, and O2 as defined by the international 10/20 system.

Procedure: The participant completed a pre-questionnaire. Electrodes attachment was followed by a 10-min stabilization period and a 10-min baseline recording period. Participants navigated specific street in VR for 9.5 min. After the completion of navigation, electrodes were detached and the participant completed a post-questionnaire. Prior to the navigation, subjects were explained about the interaction with the system and practiced sufficiently a joystick usage using left hand. During the navigation, subjects were asked to find virtual objects placed randomly within the VR. Subjects were instructed to speak out symptom whenever they felt cybersickness.

Pre- and Post-questionnaire: The subjects initially completed a pre-questionnaire that included a motion sickness susceptibility questionnaire (MSSQ) and an immersion tendency questionnaire (ITQ) before VR navigation. Each subject gave a pre-immersion rating on the malaise scale. After navigation, subject completed a post-questionnaire that included a simulator sickness questionnaire (SSQ) and a presence questionnaire (PQ) (Kennedy, 1993; Witmer and Singer, 1998). SSQ contains the list of 16 symptoms, which are rated by the subject on 4-point scale (0 = absent, 1 = slight, 2 = moderate, 3 = severe). 3 subscales derived from prior factor analysis were labeled as: Nausea (N) (nausea, stomach awareness, increased salivation, burping); Oculomotor (O) (eyestrain, difficulty focusing, blurred vision, headache); and Disorientation (D) (dizziness, vertigo). The subscales, N, O, D, are computed by summing the ratings of all symptoms that apply and then multiplying by and appropriate weight. This weight is 9.54 for N, 13.92 for D, and 7.58 for O. Total Severity score (TS) is computed by adding the sums of symptom ratings for N, O, and D and multiplying by 3.7. The frequency of cybersickness was obtained verbally whenever participants spoke out the symptom of cybersickness.

Data analysis: A stepwise multiple regression analysis was used to predict participants cybersickness scores from changes of physiological parameters and subjective variables. All ANOVA effects, correlations, and differences between means reported in this paper are statistically significant at $p < .05$.

3. Results

All subjects reported 1 (no symptoms) on the pre-immersion rating on the malaise scale. Four subjects (6.6%) among total sixty-one subjects withdrew from the experiment

because of severe cybersickness during the virtual navigation. So, data from 57 subjects (29 males, 28 females) were analyzed.

The profile of SSQ scores: The profile of the mean SSQ scores after the virtual navigation of 9.5-min is shown in Figure 1. The mean TS was 39 (SD 15.16). The profiles of the post-exposure sickness sub-scores are D (mean 49.72, SD 21.24) > N (mean 32.75, SD 13.83) > O (mean 26.83, 10.23).

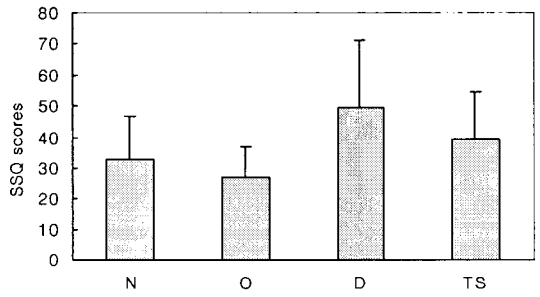

Figure 1. Mean cybersickness scores after a 9.5-min virtual navigation. Error bars represent the standard deviation of the mean. N = Nausea subscore, O = Oculomotor subscore, D = Disorientation subscore, TS = Total Severity score.

Cybersickness prediction: The results presented thus far suggest that psychophysiological responses found during the virtual navigation may herald the degree of severity in cybersickness after the virtual navigation.

Table 1. Stepwise Regression Analysis Predicting TS Score of Cybersickness from MSSQ Score, ITQ-Involvement Factor, Gastric Tachyarrhythmia, T3 Delta Relative Power, and T3 Relative Beta Power

Variables	β	*r*	*t*	*p*
MSSQ score	.43	.43	4.52	.00
ITQ sub-score	.36	.35	-3.69	.00
Tachyarrhythmia	.25	.32	2.64	.01
T3 delta power	.29	.27	3.08	.00
T3 beta power	-.27	-.30	-2.63	.01

Note. TS = Total Severity; MSSQ = Motion Sickness Susceptibility Questionnaire; ITQ = Immersive Tendency Questionnaire. R^2 = .57.

Therefore, in order to determine which variables might best predict cybersickness susceptibility, an analysis was undertaken in which measured variables were entered into a predictive model with TS score of cybersickness as the criterion variable. A stepwise regression analysis was conducted. The subjective, autonomic, and EEG variables were entered into regression equation in descending order of their correlations with the dependent variable, corrected for the effects of any independent variables that had already been entered. The criterion to enter an independent variable was F (2, 54) of at least 3.0, which corresponded to a correlation of about .20. The 12 predictor variables consisted of MSSQ score, Anxiety level, Involvement factor score in ITQ as subjective variables, gastric tachyarrhythmia, RSA, heart

period as autonomic variables, and F3 relative delta power, T3 relative delta power, F3 relative beta1 power, P3 relative beta1 power, T3 relative beta power, O1 relative alpha1 power as EEG variables. The dependent variable was the TS score of post-navigation. Five variables had adequate predictive value to enter the multiple regression equation: MSSQ score, Involvement factor score of ITQ, gastric tachyarrhythmia, T3 relative delta power, and T3 relative beta power (Table 1). These data indicated that higher levels of MSSQ, Involvement factor in ITQ, T3 relative delta power, and tachyarrhythmia and greater decreases in T3 relative beta power predict an increased severity of cybersickness symptoms. The R^2 between these variables and TS score was .57. In summary, motion sickness susceptibility of the past in transport and immersive tendency of past, change of tachyarrhythmia, and changes of delta and beta relative power of T3 site predicted how much cybersickness symptoms the participant reported.

4. Discussion

The result of multiple regression analysis supports the efficacy of examining the value of physiological responses containing autonomic variables (gastric tachyarrhythmia) and EEG parameters (T3 delta and beta powers) and subjective reports (MSSQ score, ITQ-Involvement factor score) as predictors of cybersickness susceptibility. Previous studies generally proposed autonomic variables such as heart rate, respiratory sinus arrhythmia, preejection period, skin conductance, and gastric tachyarrhythmia as predictors of motion sickness (Cowings, Suter, Toscano, Kamiya, & Naifeh, 1986; Gianaros, Quigley, Mordkoff, & Stern, 2001; Hu, Grant, Stern, & Koch, 1991). In this study, the addition of EEG variables and subjective variables as well as autonomic variables as predictors increased the value of R^2 (.57). This result indicates that predictor variables do predict cybersickness susceptibility up to 57%. We have examined the number of variables in order to find the pivotal factor of cybersickness. These analyses have produced evidence that may elucidate the role of psychophysiological activity in cybersickness during the virtual navigation. We suggest that obvious increase in gastric tachyarrhythmia, eyeblink frequency and EEG delta band in T3 site and reduction of EEG beta power in T3 mark the cybersickness and could predict the cybersickness susceptibility with MSSQ and ITQ scores obtained before the virtual navigation. In further research, the analysis of data of a larger sample of people should increase or change reliability of predictor variables.

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