# PSYCHOPHYSIOLOGICAL CHANGES DURING VIRTUAL REALITY NAVIGATION

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We examined the psychophysiological effects of navigation in a virtual reality (VR). Subjects were exposed to the VR, and required to detect specific objects. Ten electrophysiological signals were recorded before, during, and after navigation in the VR. Six questionnaires on the VR experience were acquired from 45 healthy subjects. There were significant changes between the VR period and the pre-VR control period in several psychophysiological measurements. During the VR period, eye blink, skin conductance level, and alpha frequency of EEG were decreased but gamma wave were increased. Physiological changes associated with cybersickness included increased heart rate, eye blink, skin conductance response, and gamma wave and decreased photoplethysmogram and skin temperature. These results suggest an attentional change during VR navigation and activation of the autonomic nervous system for cybersickness. These findings would enhance our understanding for the psychophysiological changes during VR navigation and cybersickness.

*Keywords :* Virtual reality, cybersickness, EEG

## I. INTRODUCTION

Virtual Reality (VR) displays potentially provide a new communication medium for human-computer interaction. VR makes it possible to transmit vivid experiences within a short amount of time [1].

Although this new technology is very promising, there exists a potential threat to the ultimate usability of VR. Some users experience discomfort during and sometimes after a session in a simulated environment [2]. Similar reactions have been observed in driving simulators and military flight simulators. This phenomenon is called simulator sickness [3]. The most common measures of simulator sickness are questionnaires and postural tests. Physiological measures, if found to be both reliable and valid, would offer objective measures of simulator sickness [4].

This report was written with two goals. The first is to examine the extent to which subjects show stable idiosyncratic physiological response patterns in virtual environments. The second is to identify characteristics in simulator sickness in VR (i. e., cybersickness) by using physiological and psychological measures. To accomplish them, we provided subject with virtual navigation for five minutes, recorded physiological measurements before, during, after navigation in the VR, and examined self-report for evaluating VR navigation.

## 2. METHODOLOGY

### *1) Subjects*

45 volunteers were recruited from a university for the experiment (25 males and 20 females, 18 to 26 years of age). All subjects were certified to be in good health, and to have normal vision and normal vestibular function.

### *2) Apparatus*

Signal acquisition: ten channels of data were gathered through a 16 bit analog-to-digital system (BIOPAC Systems, Inc: MP100WSW) with a sampling rate of 200 point per second. Five channels recorded autonomic physiological data: electrocardiogram (ECG), electroculogram (EOG), fingertip skin resistance, fingertip photoplethysmogram (PPG), and fingertip skin temperature (SKT). The rest channels recorded electroencephalogram (EEG).

EEGs were recorded from the 5 scalp loci at Fz, Cz, Pz, O1, O2 as defined by the international 10/20 system with 1.0-hz low filter, 100-Hz high filter, 5 μV/mm sensitivity, and impedances below 5 kΩ. Reference electrodes were placed on both earlobes (A1, A2) for monopolar recording. ECG signal was recorded with a Lead II configuration, right wrist to left leg. Skin conductance level (SCL), the reciprocal of basal skin resistance measures obtained with electrodes placed on the index and middle fingers of the left hand. Skin conductance response (SCR) was defined as a conductance occurring within 1-5 s.

Virtual reality system: VR system used in this study in the 3D Visual and Auditory Environment Generator (VAEG), which was developed by the Korea Institute of Science and Technology (KIST) VAEG displays 3D objects such as telephones, buildings, or small villages, using VR technologies. In this study, the 3D model was designed to simulate the inside of KIST. 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) through three channels.

### *3) Self report and other measures*

Subjects were asked to fill out pre-questionnaires that included a motion history questionnaire (MQ) and a immersion tendency questionnaire (ITQ) before navigating in the VR. After navigation, subject completed post-questionnaires that included a simulator sickness questionnaire (SSQ), a presence questionnaire (PQ), a flow questionnaire (FQ), and a questionnaire for user interface satisfaction (QUIS) [5].

### *4) Procedure*

Each session of the experiment was divided into three sections. The subjects were asked to complete pre-questionnaires in the first section. Prior to beginning the second section, each subject was given explanation about objects (10 trashcans). In the second section, subjects were asked to navigate the VR for five minutes and find ten trashcans placed randomly within the virtual environment. They were asked to speak out the number of a trashcan that attached on it. Subjects were asked to speak out symptom whenever they felt cybersickness. Physiological data were acquired for 30 second before, 5 minutes during, and 30 second after navigation in the virtual reality. After performing the object search task, subjects were asked to answer post-questionnaires about their experience.

### *5) Quantification of Data*

All channels of analog data were filtered by a band-pass filter (0-50 Hz), sampled at 200 Hz, and then reduced in the following manner. All data from before and after the navigation were summarized as mean values for 30-s epochs. For the navigation phase, data were gathered as mean values for 60-s epochs 3 times. Physiological data for 3-s epochs of cybersickness were gathered and summarized.

EEG signals, without artifacts, relating to movement and other factors were analyzed. Spectral analysis was performed by Fast Fourier Transform in the band 0-50 Hz. The EEG at each derivation was parameterized in terms of its relative power in the 5 bands, as follows: delta 0.20-3.99, theta 4.00-7.99, alpha 8.00-12.99, beta 13.00-29.99, gamma 30.00-50.00 Hz. Mean percentage of relative power at each scalp location was defined as: (Power within the band at the location/Total power across all bands at the location) × 100%.

### *6) Statistical analysis*

One-way ANOVA with repeated measures was employed for overall test and followed by Post hoc analysis (Duncan's method).

## III. RESULTS

### *1) Physiological changes during virtual navigation*

Results showed significant physiological changes during the navigation of virtual reality (Tab. I).

TABLE I

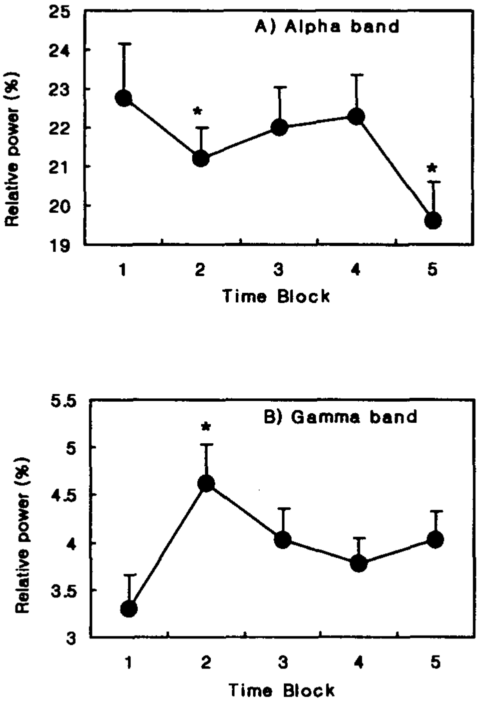
Physiological changes during navigation in a virtual reality. The values given represent the mean for all subjects tested. Percentage of relative power is presented here. * = p<0.05, n = 45.

| Parameter | Base-line | VR-initial stage | VR-middle stage | VR-final stage | Post Navigation |
|---|---|---|---|---|---|
| EEG Variables (%) | | | | | |
| Alpha Cz Power | 22.75 | 21.20* | 22.00 | 22.26 | 19.60 |
| Alpha Pz Power | 26.54 | 23.68* | 24.56 | 25.00 | 21.35 |
| Alpha O1 Power | 27.07 | 22.97* | 24.72 | 24.64 | 21.68 |
| Alpha O2 Power | 27.58 | 23.20* | 25.01 | 24.57 | 22.05 |
| Beta Fz Power | 14.19 | 16.99* | 17.01* | 17.31* | 17.42 |
| Beta O1 Power | 32.37 | 35.77* | 33.33 | 34.39 | 23.25 |
| Gamma Fz Power | 2.31 | 3.37* | 2.96 | 2.72 | 3.14 |
| Gamma Cz Power | 3.29 | 4.62* | 4.03 | 3.77 | 4.03 |
| Gamma Pz Power | 3.67 | 5.30* | 4.58 | 4.32 | 4.59 |
| Gamma O1 Power | 5.68 | 8.30* | 6.85 | 6.67 | 7.04 |
| Gamma O2 Power | 5.32 | 7.50* | 6.06 | 6.00 | 6.34 |
| Autonomic variables | | | | | |
| SCL (S) | 0.086 | 0.069* | 0.075 | 0.077 | 0.074 |
| Eye blink (number/min) | 22.10 | 13.01* | 15.90 | 17.09 | 35.62 |

### EEG

Analysis of variance on relative power of EEG to virtual reality yielded significant Time effects for each variable, beta frontal power: $F(4,44)=3.39$, $p<0.01$; gamma frontal power: $F(4,44)=5.12$, $p<0.0006$; alpha central power: $F(4,44)=2.91$, $p<0.03$; gamma central power: $F(4,44) = 5.55$, $p < 0.0003$; alpha parietal power: $F(4,44)=5.85$, $p<0.0002$; gamma parietal power: $F(4,44)=7.39$, $p<0.0001$; alpha left occipital power:

$F(4,44)=5.88$, $p<0.0002$; beta left occipital power: $F(4,44)=3.03$, $p<0.02$; gamma left occipital power: $F(4,44)=7.39$, $p<0.0001$; alpha right occipital power: $F(4,44)=6.18$, $p<0.0001$; gamma right occipital power: $F(4,44)=4.12$, $p<0.004$. Alpha central, parietal, and occipital power decreased and beta frontal and left occipital power, and gamma power all over the regions increased markedly at the initial stage of virtual navigation (Duncan test, $p<0.05$) (Fig. 1). The effect sizes for alpha decreases and beta increases at the early stage of virtual navigation were medium in size ($d > 0.6$).



FIURE 1
Percentage of relative power in alpha and gamma band at Cz during control and virtual navigation periods. Each point represents the average changes of EEG components from 45 subjects. A) alpha band, B) gamma band. Time block: 1-Baseline, 2-VR navigation-initial stage, 3-VR navigation-middle stage, 4-VR navigation-final stage, 5-Post navigation. * = p < 0.05.

### Skin conductance level

ANOVA on amplitude of SCL to virtual reality yielded a significant Time effect ($F(4/44) = 19.89$, $p<0.001$). SCL decreased markedly at the initial stage of virtual navigation (Duncan test, $p<0.05$), with some rhythmical fluctuations during navigation; it maintain to the decreased value after navigation (Fig. 2). The effect size for SCL decrease was large ($d > 1.0$).

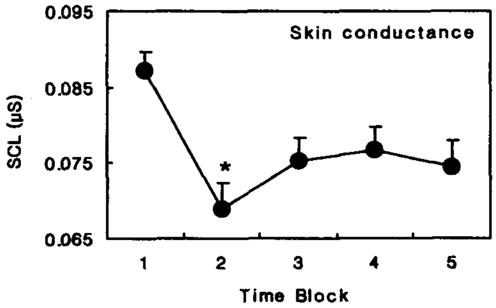


FIGURE 2
Skin conductance level for baseline and virtual navigation. * = p < 0.05. Time block: see Figure 1

### Eye blink

One-way repeated ANOVA on eye blink to virtual reality yielded a significant Time effect ($F(4/44) = 20.33$, $p<0.0001$). Eye blink decreased markedly at the initial stage of virtual navigation (Duncan test, $p<0.05$), with remaining low level during navigation and rose beyond the baseline level after navigation. The effect size for the decreased eye blink frequency was large in size ($d > 1.0$).

### *2) Physiological patterns for cybersickness in virtual reality*

Tab. II presents means for physiological variables for 32 subjects, who experienced cybersickness during virtual navigation, for the normal phase (left column) and cybersickness phase (right column). Means of

PPG, and SKT were lower, and heart rate, eye blink, and skin conductance response (SCR) were greater during cybersickness than normal period. Also, theta power was lower and gamma power was higher for cybersickness than normal phase of virtual navigation.

One-way ANOVA with two levels of phase (normal and cybersickness) and five dependent variables (PPG, SKT, SCR, heart rate, eye blink) revealed a significant main effect for phase. Individual comparisons revealed significant phase differences for each variable, amplitude of PPG: $F(1,31)=743.80$, $p<0.0001$; mean of SKT: $F(1,31)=99999.99$, $p<0.0001$; amplitude of SCR: $F(1,31)=99999.99$, $p<.0001$; heart rate: $F(1,31)=10.96$, $p<0.003$; eye blink: $F(1,31)=843.50$, $p<0.0001$. The effect sizes for the five variables individually were large (all $d > 1.1$).

Also, One-way repeated ANOVA with a within-subjects variable (phase: normal and cybersickness) and relative power of EEG as the dependent variable revealed significant main effects for phase. Individual comparisons revealed significant phase differences for each variable, theta frontal power: $F(1,31)=109.79$, $p<0.0001$; alpha frontal power: $F(1,31)=6.96$, $p<0.01$; beta frontal power: $F(1,31)=56.79$, $p<0.0001$; gamma frontal power: $F(1,31)=46.13$, $p<0.0001$; theta central power: $F(1,31)=10.75$, $p<0.003$; beta central power: $F(1,31)=9.04$, $p<0.006$; gamma central power: $F(1,31)=14.43$, $p<0.0008$; gamma parietal power: $F(1,31)=12.99$, $p<0.001$; gamma left occipital power: $F(1,31)=10.23$, $p<0.004$. The values for $d$ ranged from 0.8 to 1.0 for gamma increases. There are similar characteristics of gamma increases all over regions during cybersickness.

The data suggest that marked reduction in skin temperature and amplitude of PPG with heart rate acceleration, and increase in gamma band, SCR, and eye blink mark the cybersickness period.

TABLE II

Means (SE) of EEG and autonomic variables during normal phase and cybersickness phase of virtual navigation. The values given represent the mean for 32 subjects who experienced cybersickness and are derived from significant variables (p < 0.05).

| Parameter | Normal | Cybersickness |
|---|---|---|
| EEG Variables (%) | | |
| Theta Fz Power | 62.63(2.13) | 44.80(2.14) |
| Theta cz Power | 51.46(1.58) | 44.94(2.17) |
| Alpha Fz Power | 17.30(0.63) | 21.10(1.55) |
| Beta Fz Power | 16.88(1.46) | 27.58(1.55) |
| Beta Cz Power | 23.27(1.16) | 27.38(1.48) |
| Gamma Fz Power | 3.18(0.37) | 6.52(0.64) |
| Gamma Cz Power | 4.35(0.33) | 5.47(0.66) |
| Gamma Pz Power | 4.91(0.31) | 6.89(0.63) |
| Gamma O1 Power | 7.35(0.42) | 9.55(0.74) |
| Autonomic variables | | |
| SCL (S) | 0.074(0.004) | 0.090(0.004) |
| Eye blink (number/min) | 15.05(0.19) | 36.00(0.40) |
| skin temperature | 93.79(0.82) | 77.51(0.74) |
| heart rare (bpm) | 74.32(1.99) | 80.69(2.10) |
| photoplethysmogram | 106.30(3.05) | 87.93(2.82) |

### 3) Subjective ratings and physiological parameters

Relations within subjective parameters were found primarily calculated separately. SSQ rating appeared correlated significantly with ITQ and QUIS ratings (r = 0.418; p < 0.05, two-tailed, r = 0.461; p < 0.05, two-tailed). PQ rating correlated significantly with QUIS rating (r = 0.415; P < 0.05, two-tailed).

Relations between subjective parameters and physiological parameters were also calculated. FQ rating correlated significantly with heart rate (r = 0.38; p < 0.05, two-tailed). SSQ rating correlated significantly with theta frontal power and theta central power ($r = -0.42$; $p < 0.01$, two-tailed, $r = 0.40$; $p < 0.05$, two-tailed). Also, QUIS rating correlated significantly with theta occipital power and alpha frontal power ($r = 0.41$; $p < 0.05$, two-tailed, $r = 0.37$; $p < 0.05$, two-tailed).

## IV. DISCUSSION

The most consistent finding was that during the course of a vigil, SCL decreased significantly [6]. Skin conductance response is a marker of orienting-attention swiching to environmental stimuli that are novel or significant [7]. Alert attentiveness is characterized by marked reduction in skin conductance responses and eye blink, desynchronized EEG, maintained fast low-amplitude, dilation of cerebral blood vessels and constriction of peripheral blood vessels, and increased sensitivity of the sense organs [8]. These physiological response patterns are similar to the pattern observed at the initial stage of virtual navigation in the current study. The EEG pattern for intake task that require attention to stimuli was studied by Valentino and Dufresne [9]. They reported that beta and gamma during task were greater with on hemisphere differences. The EEG pattern was similar to that of navigation in virtual reality in that beta and gamma during navigation were greater than baseline.

We suggest that skin conductance level and eye blink reduction with greater beta and gamma at the initial stage of virtual navigation reflect the requirement of attention. And, after initial stage of VR navigation, decreased physiological changes may reflect reduction of attention load by adaptation.

The data during cybersickness showed marked increase in eye blink, SCR, and gamma band and reduction in skin temperature and amplitude of PPG with heart rate acceleration. On the occasion of motion sickness with body movement is characterized by decreased PPG and increased respiration rate, skin conductance, and heart rate [10]. The physiological response pattern is similar to the pattern observed during cybersickness without body movement in the current study. Movement of the field of vision, without movement of the body, can cause some of the signs and symptoms similar to motion sickness. It has been reported that the sickness by movement of sickness. But the severity of cybersickness in this virtual reality showed individual difference.

Physiological patterns at the cybersickness in this study were very similar to that of motion sickness except to electroencephalographic characteristics. Comparison of electroencephalograms and histories of motion sickness did not reveal any correlation [11].

We suggest that marked increase in eye blink, SCR, and gamma band and reduction in skin temperature and amplitude of PPG with heart rate acceleration mark the cybersickness and could discriminate this phase during virtual navigation.

Correlation analysis of subjective parameters and physiological parameters showed relationship between two measures. FQ measured degree of interests and satisfaction for virtual navigation. Relation of heart rate and FQ showed that increase heart rate correlate the interest for the virtual navigation. Negative correlations between SSQ and theta power at Fz and Cz may relate with reduction of theta power for cybersickness.

## V. CONCLUSION

This study aims to extract the characteristics of the physiological changes and the cybersickness in the virtual reality. These data support our contention that physiological patterns are sufficiently consistent so as to serve as an objective indicator of cybersickness levels. Our approach has been to identify the pattern of autonomic nervous system and EEG responses associated with cybersickness. We hope that these results provide preliminary physiological basis for virtual reality and cybersickness and are used to evaluate human-based virtual reality system.

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