광 혈류 신호의 주파수 파워 특성과 0차 미분값을 이용한 가상환경의 스트레스 평가

남영한, 김현택*, 고희동**, 박광석***
서울대학교 공과대학 협동과정 의용생체공학 전공, *고려대학교 심리학과, **한국과학기술원 영상미디어센터, ***의과대학 의공학교실

Assessment of stress in virtual reality environment using power spectral density ratio and second derivative of photoplethysmogrphy

Y.H. Nam, H.T. Kim*, H.D. Ko**, K.S. Park***
Interdisciplinary Program in Medical and Biological Engineering Major, Seoul National University, *Dept. of Psychology, Korea University, **Image Media Research Center, KIST, ***Department of Biomedical Engineering, College of Medicine, Seoul National University

Abstract

There are many people who suffer from simulation sickness when immersing in virtual reality. In this study, we analyzed two photoplethysmogram(PPG) parameters - a second derivative parameter and power spectral density ratios - in order to relate PPG parameters with simulation sickness. 36 young, healthy subjects were participated in the experiment, and each subject was equipped with a PPG electrode during his or her immersion. Simulation sickness section was defined as a 7-second section which starts from the point where a subject reported simulation sickness, and normal section as a same-length section where no physical stimuli was presented to him or her. We compared the PPG parameters of the simulation sickness sections with the normal sections, -d/a ratio is believed to have lower value during vasodilation and higher value during vasoconstriction, however, we could not find much difference in the parameter between normal and simulation sickness sections. We also compared 1 to 10Hz power spectral density ratios in normal sections with in simulation sickness section, and found that 6 density ratios among them have different value. Therefore, the density ratios might be utilized as parameters to detect simulation sickness of subjects.

Keywords ; photoplethysmograpy(PPG), simulation sickness, second derivative of PPG(SDPTG), power spectral density ratio

INTRODUCTION

VR(Virtual Reality) system has been widely used for various purposes. However, during immersing in virtual environment, many people suffer from simulation sickness ; which includes various symptoms such as nausea, vertigo, disorientation, malaise, and dizziness.[1] Each symptom comes from a specific physiological reasons. For example, nausea is evidence of altered autonomic (especially parasympathetic) activity, such as skin pallor, increased perspiration, and occasionally, hypotension and bradycardia. [2]

Digital photoplethysmogram(PPG) measures the amount of the light that is absorbed by hemoglobin. Kenji et al.[3] discussed that PPG signal is related with the blood volume changes in the blood vessel - vasodilation and vasoconstriction. They also discussed that the neagtive d/a ratio of second derivative of PPG(SDPTG) decreases significantly with vasodilation.

In this study, we compared - d/a ratio and power spectral density ratios of PPG signal in simulation sickness section with in normal section. Furthemore, we constructed an automatic PPG signal analysis system that can be used for on-line data analysis or bio-feedback.

METHODS

1. Subjects and signal acquisition

Thirty six young, healthy subjects(19 males and 17 females) with mean±SD age of 21.4±3.03 years navigated a virtual reality environment. The overall experiment was composed of one minute pre-immersion period, 9.5 minute immersion period, and one minute post-immersion period. During the experiment, PPG signal was measured from the middle fingertip of a subject, and sampled at 400Hz with other electrophysiological signals including EEG, ECG, EOG, etc.

2. Data analysis

One period of PPG signal is automatically determined by highpass filtering(fc=0.5Hz), lowpass filtering (f_c=10Hz), normalizing, thresholding and some other techniques. The reason why we filtered the signal at 10 Hz is that PPG signal can be reconstructed by first 10 harmonics at low error rate.[4] Determined one-period PPG time series is depicted in Fig. 1 and second derivative of PPG(SDPTG) is shown also in Fig. 1. The second derivative consists of a, b, c, and d peaks in systole and e peak in diastole as marked in Fig 1.

Each peak amplitude is processed

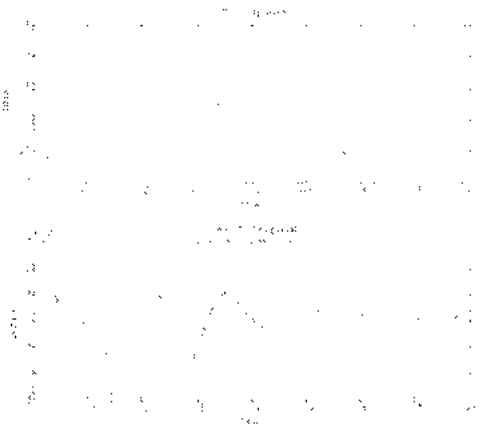

Fig 1. A typical PPG one-period waveform(upper) and SDPTG for this one-period waveform

Parameters	normal section parameters (averaged value)	Simulation sickness section parameters (averaged value)	p-value
-d/a ratio	0.1650	0.1518	0.13
Power spectral density ratios for each frequency (Hz)			
1	0.04363	0.02400	0.013*
2	0.3624	0.3797	0.43
3	0.5419	0.5258	0.45
4	0.02393	0.02896	0.040*
5	0.01925	0.02855	0.0032**
6	0.007807	0.01135	0.087
7	0.0006732	0.001203	0.00081**
8	0.0002465	0.0003046	0.2513
9	0.00007400	0.00009698	0.016*
10	0.00003435	0.00005907	0.024*

Table 1 Statistical analysis of the parameters for normal section and nausea section for all subjects (*p<0.05, **p<0.01)

automatically by the zerocrossing points of lowpass-filtered derivative of SDPTG. A simulation sickness section was defined as a 7-second section which starts from the point where a subject reported simulation sickness, and normal section as a same-length section where no physical stimulus was presented to him or her.

In each section, periods were analyzed for each period, a -d/a parameter was calculated in a period, and then averaged for all periods in a section. A power spectral density ratio for a frequency was calculated by dividing the frequency power spectral density by 1-10Hz band power. For each subject, all simulation sickness sections and all normal sections (7-second length windows non-overlapped in 1 minute pre-immersion section) are analyzed and compared.

RESULTS

The comparison result of the grand averaged PPG parameters in the simulation sickness sections with in the normal sections is shown in Table 1. -d/a ratios is not statistically different in two sections. ($p>0.05$) 6 power spectral density ratios out of 10 were statistically different, above all, 5 and 7Hz density ratios were strongly statistically different. Among statistically different ratios, 1 and 7 Hz density ratios were bigger in normal sections, on the contrary, 4, 5, 9, 10 Hz ratios were smaller in normal sections than simulation sickness section.

DISCUSSION

-d/a ratios did not have statistical difference between normal sections and simulation sickness sections in value. -d/a ratios were believed to reflect vasodilation or vasoconstriction, it is possible that -d/a ratio could not reflect

the complex essence of simulation sickness, since simulation sickness has a variety of symptoms each of which has different physiological characteristics.

However, 6 parameters of power spectral density ratios were statistically different, which implies that these spectral ratios might be utilized as parameters detecting simulation sickness based on bioelectric signals.

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