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The influence of polarized 3D display on autonomic nervous activities

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ABSTRACT

The spectral analysis of Heart Rate Variability (HRV) can be used for assessing the autonomic nervous activities and further the physiological conditions of subjects. This study intended to explore whether or not people would have fatigue, faintness and other kinds of uncomfortable conditions after watching a 3D film by using HRV measures as the objective physiological indices, in addition to other subjective physiological indices.

Twenty men aged 22 ± 2 experienced watching 3D films and 2D films and were served as the controls of themselves. As the controls, the subjects had to rest at the same place. All subjects were are randomized for taking different experiences, and the electrocardiographic (ECG) signals were recorded during the whole process. The researchers could obtain the indices of the autonomic nervous activities before and after experiencing 3D and 2D movies with the help of spectral HRV analyses, along with the objective physiological information. The subjects were requested to fill out the questionnaire for the subjective feelings after the movie experiences.

It was found that the subjects' high-frequency power (HFP) representing parasympathetic nervous activities decreases after watching a 3D film. The sympathetic and parasympathetic nerve activities before and after watching a 2D film were not significantly different. The subjects complained that they felt dizzy, had headaches, and got visual fatigue while watching a 3D film.

This study found that the subjects' parasympathetic nerve activities were reduced after watching a 3D film, indicating that watching a 3D film would make people uncomfortable and tired. This result was the same as that of the questionnaire. Thus, HRV analyses could be an objective physiological index for discomfort as viewing 3D films.

1. Introduction

People have been making stereo pictures since the 17th century and have achieved a historical breakthrough in the development of 3D display technologies in the past 20 years. Although one of the main research directions is watching 3D displays without glasses at present [1–4], watching 3D displays with glasses recently is still the main trend. Regarding 3D displays with glasses, polarized glasses and shutter glasses are two commonest ways [5]. The polarized glasses are commonly used in theaters, as they are lighter, cheaper, no electronics and no radiation by comparison. The polarized 3D display technology is easy to implement in the theaters. In addition, people do not have to worry about wrong images caused by the different speed of glasses switches from that of screen displays.

At present, 3D display technologies are mainly used for both eyes watching images with different angles at the same time. The images can be transferred to the brain through retinal nerves and create pictures with different depths. Wickens et al. [6] suggested that the main physiological factors in the sense of depth were binocular parallax, convergence and accommodation.

With the trend of 3D films, more people have paid attention to ergonomic study on 3D displays to see whether people are comfortable and safe while watching a 3D film.

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The methods of 3D ergonomic study are visual fatigue measurement, survey assessment, blood pressure measurement, and other kinds of physiological signal measurements [1]. The majority of which are visual fatigue measurement and survey assessment. Kooi and Toet [7] found that binocular parallax was the main factor in people feeling uncomfortable while watching a 3D film. In addition to binocular parallax, Lambooij and IJsselsteijn [8] also pointed out that other factors could make people uncomfortable, such as different speeds of making images, images information (insufficient depth information in the incoming data signal yielding spatial and temporal inconsistencies), nonsymmetrical stereoscopic images, and unnatural blur. Ntuen et al. [9] asked the subjects to do the same experiments with 2D and 3D displays and compared these two results. The subjects were asked to correctly point out the ball randomly shown on the screen being close to the target and the color of the target. It was shown that the 3D group subjects had greater accuracy as compared with the 2D group. Thus, watching 3D films was easier for people getting visual fatigue by comparison.

On the other hand, it was stated that people would have faintness, fatigue and other uncomfortable situations when sympathetic and parasympathetic nerve systems were not balanced [10]. Kim et al. [11] investigated the psychophysiological effects of 3D artifacts included changes not only in subjective symptoms of visual fatigue and the depth sensation, but also to heart and brain activity. Therefore, we used HRV analysis to confirm the influence of watching the 3D film. HRV is a non-invasive index and can refer to the balance between autonomic nerves and the cardiovascular system as HRV is highly sensitive, measurable, and repetitive.

The HRV measures and the survey are normally used as the physiological indices for virtual reality experiments. It is found that visual-vestibular conflict resulting from visual reality would affect autonomic nervous modulation [12]. Chao et al. [13] compared with 3 kinds of 3D displays by visual acuity, binocular diopter, pupil size, binocular intraocular pressure, binocular High-Frequency Components of accommodative micro fluctuations, contrast sensitivity and critical flicker fusion frequency and a questionnaire. The result showed sympathetic and parasympathetic nerve systems appropriately control the physiological feedbacks by varying the ratio of the signals from the sympathetic and parasympathetic nervous systems when viewing 3D displays. Li et al. [14] found that the subjects' heart rates decreased after participating in visual car racing experiments. Ohyama et al. [15] used a polarized filter system to establish a visual reality and move visual subjects randomly to induce carsickness. They pointed out the decreasing index of sympathetic and vagal activities, low frequency power, after the experiment. In the Japanese event, Pokemon shock, many children were sent to hospitals after watching a certain explosion scene. This scene was displayed by multi-color flashes to create the persistence of vision. It was found that only five to ten percents of the children sent to hospitals were the patients with photosensitive epilepsy [16]. Yamb et al. [17] analyzed HRV, with personality survey and visual reality as the research methods, to explore the relationship between personality and visual stimulation. The subjects had to wear head mount systems and played games in the visual reality made by shooting game programs. It was discovered that there was consistency between autonomic nerve changes and mental tendency. The results could find the ones with sensitive visual stimulation beforehand and further decrease the risk of photogenic epilepsy because of visual-reality images.

In this study, we investigated the influence of polarized 3D display on autonomic nervous activity for long time by using HRV analysis. It is a direct way to detect the variation of parasympathetic and sympathetic nervous systems. This study planned to explore HRV by recording ECG and then analyze HRV parameters [18,19] to understand the changes in sympathetic and parasympathetic nerve activities.

This study proposed not only HRV analyses as the objective indices but also the questionnaire survey as subjective physiological indices. As a result, this study suggested that the subjects' parasympathetic nerve activities significantly decrease while watching 3D film and the subjects feel uncomfortable and fatigued. This study also suggested that the influence of 3D films on patients with cardiovascular diseases should be a research-worthy issue.

2. Materials and methods

2.1. Subjects

The subjects recruited were 20 healthy men with the mean age of 22 ± 2 (see Table 1), lest the HRV parameters [20,21] were affected by different genders and ages. All subjects did not have any medical illnesses for at least one year, had no alcoholism or drug abuse, and did not receive medical treatments for acute myocardial infarction, diabetes, chronic renal failure, congestive heart failure, etc. They also did not take antidepressant or other medicines which would affect autonomic nervous activities [22–26]. The study followed Declaration of Helsinki in 1975 and was approved by Institution's Human Research Committee. All subjects knew all relevant procedures, and did not have any food or drink with caffeine or alcohol 8 h before the experiment. Subjects should not have lack sleeping time at the night before doing the experiment. All subjects had slept well and the sleeping time was more than 8 h in this experiment.

The visual acuity of all subjects were recorded and checked their visual acuity with their glasses were corrective before implementing the experiment. And the binocular vision tested was implemented with a Randot Stereo test (shown as Fig. 1) before the experiment for confirming subjects can see 3D image well. The Graded circle test is from 400 to 20 s of arc (shown as Table 2).

2.2. Experimental environment

According some HRV researches which are useful for the method of experiment design, the place for the study was a dark room which looked like a mock theatre with the room temperature 25 ± 2 °C [25]. The polarized filter system of 3D display technologies was used, and the 3D film was projected onto a 60-in. screen. All subjects wore polarized glasses during the whole process. The researchers clipped a 10-min film from a computer game, METAL GEAR SOLID IV, as the experiment film. It is an action-adventure video. The depth perception of the 3D video was consistent during all time and the depth perception was limited for avoiding people feeling uncomfortable temporarily. The distance between the subject and the screen was 2 m [26].

2.3. Electrocardiography (ECG)

All subjects received the experiments at the same time period (from 6:00 p.m. to 10:00 p.m.) during the day. During the procedure, all subjects sat properly, relaxed, and kept their mind clear

Table 1
Baseline characteristics of the subjects.

Item	Average
Age (years)	22.7 ± 1.9
Body height (m)	1.72 ± 0.06
Body weight (kg)	66.2 ± 11.1
BMI (kg/m^2)	22.3 ± 3.2

Fig. 1. Randot Stereo tests (Stereo Optical Company, Inc.).

Table 2
Graded circle test.

Object	1	2	3	4	5	6	7	8	9	10	
Disparity	400	200	140	100	70	50	40	30	25	20	Unit (arcsec)

without talking lest their heart rates were influenced by external factors. All subjects were taken the ECG measurement while watching the film. Biopac MP150 (model ECG 100C, AcqKnowledge; Biopac Systems, Santa Barbara, CA, USA) was applied to the subjects by chest Lead II.

2.4. Experimental procedure

There were 3 groups in the experiment, including a 3D group, a 2D group and a control group. Control group was implemented for understanding how the environment affect the subjects. All subjects took a 5 min rest and then started the experiments. For the 3D group, the subjects sat on the couch with a 10 min ECG, watched a 10-min 3D film, turned the film off and took another 10 min rest (see Fig. 2 for the procedure). The procedure of the 2D group was the same as that of the 3D group, except that the subjects watched a 2D film instead of a 3D film. As for the control group, the subjects sat at the same place for 30 min without doing anything. During the experiment, subjects could not talk and subjects' eyes were closed and relaxed.

All subjects joined in the three groups in random order. Each one could finish one experiment from different conditions in one day and one room. Thus, every subject should spend 3 days to finish all experiments (30 min in 1 day). After the experiments, the subjects were requested to fill in a survey (see Table 3) as the subjective physiological index. During the experiment, once the subject felt uncomfortable, such as breathing difficulty, paleness, dizziness or faint, or wishing to stop the experiment, the experiment would be stopped.

2.5. Analysis of heart rate variability

HRV is measured by measuring the variation in the beat-to-beat intervals within certain time period. In general, HRV is influenced by breath, blood pressure, endocrine, and emotion and can be used for observing the interaction between autonomic nervous activities and the sinoatrial node [10].

The R–R intervals were obtained from the ECG records. R–R interval is the interval from the peak of one complex to the peak of the next as shown on an electrocardiogram. It is used to assess the ventricular rate. When a subject had sinus arrest, atrial arrhythmia or ventricular arrhythmia, the abnormal R–R interval would be deleted. A series of 512 normal R–R intervals were used in spectral analyses. When a subject had more than 5% abnormal R–R intervals because of arrhythmias, the subject would not be included in the study. The R–R intervals were processed by fast Fourier transform to give the HRV spectrum. Its total power (TP) is the sum of the power spectral density within the range of 0.01–0.4 Hz. Very Low frequency power (VLFP) is the sum of the power spectral density within the range of 0.01–0.04 Hz. Low frequency power (LFP) is the sum of power spectral density within the range of 0.04–0.15 Hz. This usually refers to the combination of sympathetic and parasympathetic nerve activities. High frequency power (HFP) is the sum of power spectral density within the range of 0.15–0.4 Hz, which normally indicates parasympathetic nerve activities. *n*LFP (shown as Eq. (1)) and *n*HFP (shown as Eq. (2)) are normalized values from LFP and HFP. Sympathetic nerve activities have been shown to correlate positively with anxiety and acute stress disorder; while the parasympathetic nerve activities are associated with a decrease in blood pressure and relieved mood.

$$nLFP = \frac{LFP}{TP - VLFP} \tag{1}$$

$$nHFP = \frac{HFP}{TP - VLFP} \tag{2}$$

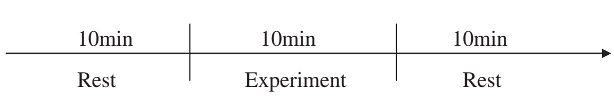

Fig. 2. Experimental procedure.

2.6. Statistical analysis

The SigmaStat statistical software (SigmaStat statistical software, Jandel Scientific, San Rafael, CA, USA) was used for analyzing the HRV statistics. Repeatedly measuring ANOVA with *post hoc* Student–Newman–Keuls tests was used for comparing and analyzing the statistics of the 2D, 3D and control groups. *T*-test was used for comparing and analyzing the results of the questionnaire from 3D and 2D Group.

3. Results

Each experiment was divided into three sections (10 min respectively) to give the power spectra of HRV in section one, two and three for the assessment of sympathetic and parasympathetic nervous activities. The total power contains VLFP, LFP and HFP. According the report from the European Society of Cardiology and the North American Society of Pacing and Electrophysiology [10], the representation of LFP and HFP emphasizes the controlled and balanced behavior of the two branches of the autonomic nervous system. Thus, we emphasized to discuss the variation of HFP and LFP for understanding how the autonomic nervous system varied in this study. The results of self-comparison are shown in Fig. 3 and the results of group-comparison are shown in Fig. 4. The degrees of freedom in the different group is 19.

3.1. Self-comparison in each group

The results of self-comparison are shown as Fig. 3 and Table 4. In the 3D group, the value of LFP in Section 3 significantly increased as compared to those in Sections 1 and 2 ($p < 0.05$). LFP increased from 371.8 ms^2 in Section1 to 608.4 ms^2 in Section 3. As for HFP, its value in Section 2 significantly decreased as compared to those in Sections 1 and 3. In the 2D group, LFP and HFP were not significantly different among Sections 1–3. In the control group, the value of LFP in Section 3 was significantly greater than those in Sections 2 and 3. The value increased from 500.8 ms^2 in

Table 3
the questionnaire for subjective fatigue.

When watching the film, did you have the following symptoms?	Strongly disagree	Disagree	Partly disagree	Partly agree	Agree	Strongly agree
1. Was the viewing distance suitable for you?	1	2	3	4	5	6
2. Was the image blurred?	1	2	3	4	5	6
3. Did you need more attention to watch the film?	1	2	3	4	5	6
4. Were you impatient when you watched the film?	1	2	3	4	5	6
5. Did you feel uncomfortable when you watched the film?	1	2	3	4	5	6
6. Did you get tired eye when you watched the film?	1	2	3	4	5	6
7. Were you dizzy when you watched the film?	1	2	3	4	5	6
8. Did you have headaches when you watched the film?	1	2	3	4	5	6

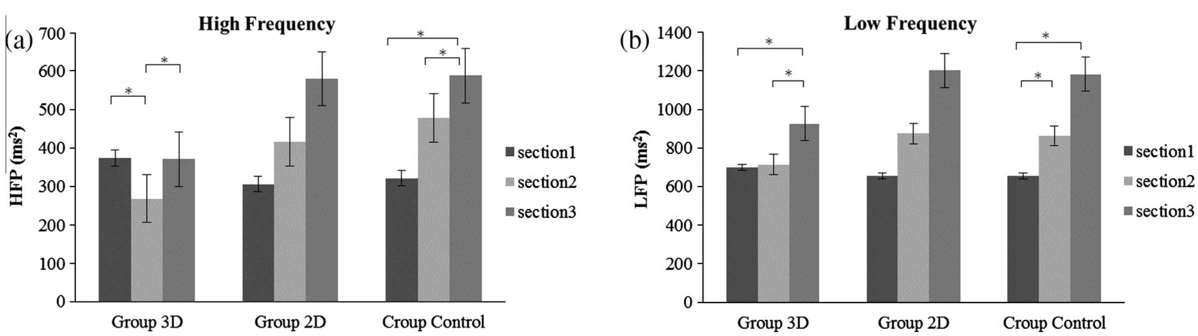

Fig. 3. Results of (a) HFP and (b) LFP, $^{*}p < 0.05$.

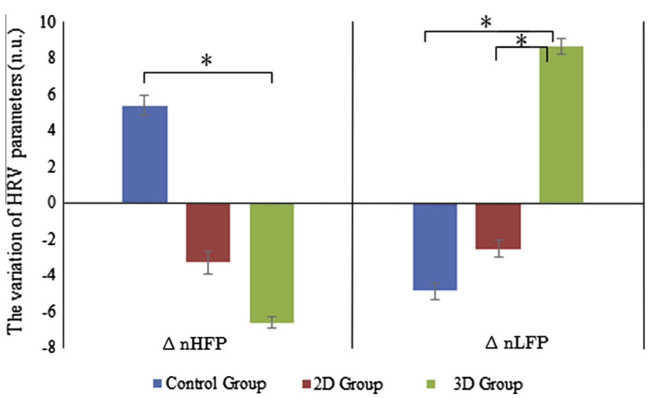

Fig. 4. Results of (a) ΔHFP ($F = 4.151$; effect size = 0.39), (b) ΔLFP ($F = 3.672$; effect size = 0.63), $^{*}p < 0.05$.

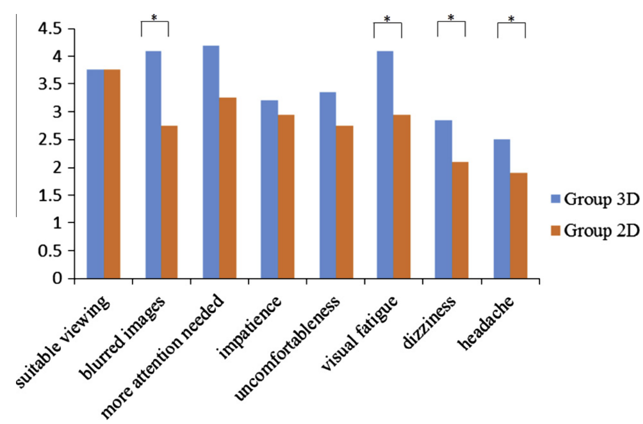

Fig. 5. The result of the questionnaire, $^{*}p < 0.05$.

Table 4
The parameters of statistics for Self-comparison.

HFP	*F*-score	Effect size	LFP	*F*-score	Effect size
Group 3D	4.13	0.58	Group 3D	4.51	0.47
Group 2D	5.78	0.31	Group 2D	5.51	0.28
Group Control	3.87	0.47	Group Control	4.49	0.49

Section 1 to 1022.4 ms^2 in Section 3. Similarly, the HFP in Section 3 increased significantly as compared to those in Sections 1 and 2.

3.2. Group-comparison

The variation of normalized HFP and LFP between Sections 1 and 2 in all groups were compared. The value of ΔHFP in the control group was significantly greater than those in the 3D group. ΔHFP decreased from 5.4 in the control group to −6.6 in the 3D group. For ΔLFP, the value in the control group was significantly decreased than in the 3D group and the value in the 2D group was also significantly decreased than in the 3D group. ΔLFP increased from −4.9 in the control group to 8.6 in the 3D group and from −2.5 in the 2D group to 8.6 in the 3D group.

All subjects were requested to fill in the questionnaire, which served as a subjective physiological index, after finishing the 3D and 2D experiments. It was found that the subjects of the 3D group were prone to have blurred images, visual fatigue, dizziness and headaches and the need of more attention, as compared to those in group 2D (Fig. 5).

4. Discussion

According to the research of Ohyama et al. [15], people could understand the influence between visual reality and autonomic nervous activities. However, this experiment only discussed the visual reality created by 3D displays, including the contents of random moving visual subjects. In this study, the experiment focused not only on the 3D group but also the 2D group and the control group to assess the influence of 3D films on humans.

Polarized 3D displays are lighter, convenient and user-friendly by comparison; therefore, this study explores the influences on autonomic nervous activities by a polarized 3D display and uses sympathetic and parasympathetic nerve activities represented by LFP, HFP, Δ*n*LFP and Δ*n*HFP of HRV as the objective physiological indices. In addition, the designed surveys act as the subjective physiological indices. Each experiment is divided into 3 parts, including before watching the film (Section 1), during watching the film (Section 2) and after watching the film (Section 3). This study explores the physiological changes in the 3D and 2D groups as compared with the control group.

Section 1 is set as the baseline. The index of parasympathetic nerve activities, HFP, decreases while the subjects are watching a 3D film, but increases after watching the 3D film. There is no significant difference in HFP among 3 sections during watching a 2D film. In the control group, HFP tends to increase gradually. On the other hand, the variations of *n*HFP form Section 1 to Section 2 in the 2D group and 3D group are less than in the control group; the variations of *n*LFP form Section1 to Section 2 in the 3D group is more than in the control group and control group. Since parasympathetic nerve activities are associated with the decrease in blood pressure and relieved mood [27,28], it is speculated that the experimental environment might relieve the subjects' moods via an increasing HFP in the control group. However, the subjects' HFP obviously decreases while watching a 3D film at the same place. This finding suggests that the subjects might be uncomfortable and pressured while watching a 3D film.

Not only does this study focus on the balance between sympathetic and parasympathetic nerve activities, but also observe human discomfort resulting from watching 3D films. The questionnaire is also analyzed and found that it is easy for the subjects having faintness, headaches, and visual fatigue and blurred images. The result of the subjective physiological index is consistent with the objective one, pointing out that it is possible to have discomfort while watching a 3D film.

Apart from HRV analyses, visual fatigue and survey, there are other ergonomic studies on 3D technologies. Marrufo et al. [29] studied the sense of visual perception. The subjects were requested to watch the targets randomly shown on the screen. The results showed that the subjects' β wave clearly increased and α wave decreased when watching a 3D image. When the person was awake, cautious and highly positive, his β waves increased. Nevertheless, when a person was quiet and relaxed, his/her α wave increased. Thus, the reason of changing brain waves might be that it consumed more energy to experience the area when the brain perceived the space reaction. The results of Marrufo et al.'s experiment also explained why it was hard for people to relax while watching a 3D film.

Oyamada et al. [30] explored 3D films with different contents via the polarized filter system. The 3D films included a drive recorder clip, a subject moving randomly, and a plot. The results showed that people's blood pressure tended to increase after watching a 3D film with a plot. The researchers chose a film with a plot, and the results showed that the subjects' parasympathetic nerve activities decreased after watching a 3D film. A decrease of parasympathetic nerve activities meant that the blood pressure tended to increase [27]. This is the same as the result of Oyamada's study.

Furthermore, HRV can refer to the physiological situation and act as an index for sudden cardiac death and cardiac arrhythmia [31]. Marc et al. stated that a decrease of HFP could reflect a subject's discomfort and served as a warning for patients with cardiovascular diseases. Previous studies showed that it was easy for patients with cardiovascular diseases and hypertension getting excited and decreasing parasympathetic nerve activities by comparison [32,33]. It was also reported that the one who suffered from sudden death after watching a 3D film in Taiwan had hypertension [34]. According to this study, present 3D films broadcasted by a polarized display, which is the main and the most convenient one, would cause a decrease of the subjects' parasympathetic nervous activities. In this study, all subjects are the healthy volunteers. Thus, even if sympathetic and parasympathetic nervous system activity was changed by 3D viewing, its maybe not a big problem for health people. However, its maybe a risk for some patients with cardiovascular diseases and hypertension when their sympathetic and parasympathetic nervous system activity was changed quickly and more. Thus, the result of the present study suggests that the influence of 3D films on patients with cardiovascular diseases and hypertension should be a research-worthy issue and it will be the outlook in our team. And on the other hand, we implicated HRV analysis can help display designers to confirm the 3D contents they designed are without risk of fatigue and other uncomfortable situations.

5. Conclusion

The development of 3D display technologies is one of the priorities in the 21st century. The present study intends to find ways for people enjoying watching 3D films without getting harmed. This is one of the important issues in the development of 3D display technologies.

In order to explore how 3D films influence human physiology, this study uses HRV analyses and questionnaire survey as the objective and subjective physiological indices. As a result, this study suggests that the subjects' parasympathetic nerve activities significantly decrease while watching 3D film and the subjects feel uncomfortable and fatigued. This study also suggests that the influence of 3D films on patients with cardiovascular diseases should be a research-worthy issue.

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Reference

[1] J.Y. Son, B. Javidi, K.D. Kwack, Methods for displaying 3 dimensional images, Proc. IEEE (Special Issue on: 3-D Technologies for Imaging & Display) 94 (2006) 502–523.
[2] J.Y. Son, B. Javidi, S. Yano, K.H. Choi, Recent developments in 3-D imaging technologies, J. Disp. Technol. 6 (2010) 394–403.
[3] C.Y. Chen, Q.L. Deng, H.C. Wu, A high-brightness diffractive stereoscopic display technology, Displays 31 (2010) 69–174.
[4] C.Y. Chen, M.C. Chang, M.D. Ke, C.C. Lin, Y.M. Chen, A novel high brightness parallax barrier stereoscopy technology using a reflective crown grating, Microw. Opt. Technol. Lett. 50 (2008) 1610–1616.
[5] T. Kawai, 3D displays and applications, Displays 23 (2002) 49–56.
[6] C.D. Wickens, S.E. Gordon, Y. Liu, An Introduction to Human Factors Engineering, Addison Wesley, Longman, US, 1997. p. 95.
[7] F.L. Kooi, A. Toet, Visual comfort of binocular and 3D displays, Displays 25 (2004) 99–108.
[8] M. Lambooij, W. IJsselsteijn, Visual discomfort and visual fatigue of stereoscopic displays: a review, J. Imaging Sci. Technol. 53 (2009) 030201–030214.
[9] C.A. Ntuen, M. Goings, M. Reddin, K. Holmes, Comparison between 2-D and 3-D using an autostereoscopic display: the effects of viewing field and illumination on performance and visual fatigue, Int. J. Ind. Ergon. 39 (2009) 388–395.
[10] M. Malik, Heart rate variability: standards of measurement, physiological interpretation, and clinical use, Circulation 93 (1996) 1043–1065.
[11] S. Kim, J. Yoshitake, H. Morikawa, T. Kawai, O. Yamada, Psycho-physiological effects of visual artifacts by stereoscopic display systems, SPIE-IS&T 7863 (2011).
[12] H. Akiduk, S. Nishiike, H. Watanabe, K. Matsuoka, T. Kubo, N. Takeda, Visual-vestibular conflict induced by virtual reality in humans, Neurosci. Lett. 340 (2003) 197–200.
[13] W.C. Chao, C.W. Chen, R.L. Dong, Y.S. Chen, An ergonomic evaluation of stereoscopic and deadzone-free autostereoscopic three-dimensional displays, SID 43 (2012) 887–890.
[14] Z. Li, K. Jiao, M. Chen, C. Wang, Reducing the effects of driving fatigue with magnitopuncture stimulation, Accid. Anal. Prevent. 36 (2004) 501–505.
[15] S. Ohyama, S. Nishiike, H. Watanabe, K. Matsuoka, H. Akizuki, N. Takeda, T. Harada, Autonomic responses during motion sickness induced by virtual reality, Auris Nasus Larynx 34 (2007) 303–306.
[16] http://edition.cnn.com/WORLD/9712/17/japan.cartoon/.
[17] T. Yambe, M. Yoshizawa, S. Fukudo, H. Fukuda, R. Kawashima, K. Shizuka, S. Nanka, A. Tanaka, K. Abe, T. Shouji, M. Hongo, K. Tabayashi, S. Nitta, Can

personality traits predict pathological responses to audiovisual stimulation, Biomed. Pharmacother. 57 (2003) 83–86.
[18] D. Liao, R.W. Barnes, L.E. Chambless, R.J. Simpson Jr., Paul Sorlie, Gerardo Heiss, Age, race, and sex differences in autonomic cardiac function measured by spectral analysis of heart rate variability – the ARIC study, Am. J. Cardiol. 76 (1995) 906–912.
[19] J. Zhang, Effect of age and sex on heart rate variability in healthy subjects, J. Manip. Physiol. Ther. 30 (2007) 374–379.
[20] F. Lombardi, G. Sandrone, S. Pernpruner, Heart rate variability as an index of sympathovagal interaction after acute myocardial infarction, Am. J. Cardiol. 60 (1987) 1239–1245.
[21] M. Lishner, S. Akselrod, V.M. Avi, O. Oz, M. Divon, M. Ravid, Spectral analysis of heart rate fluctuations: a non-invasive, sensitive method for the early diagnosis of autonomic neuropathy in diabetes mellitus, J. Auton. Nerv. Syst. 19 (1987) 119–125.
[22] S. Akselrod, M. Lishner, O. Oz, J. Bernheim, M. Ravid, Spectral analysis of fluctuations in heart rate: an objective evaluation of autonomic nervous control in chronic renal failure, Nephron 45 (1987) 202–206.
[23] J.P. Saul, Y. Arai, R.D. Berger, L.S. Lilly, W.S. Colucci, R.J. Cohen, Assessment of autonomic regulation in chronic congestive heart failure by heart rate spectral analysis, Am. J. Cardiol. 61 (1988) 1292–1299.
[24] K.J. Bar, W. Greiner, T. Jochum, M. Friedrich, G. Wagner, H. Sauer, The influence of major depression and its treatment on heart rate variability and papillary light reflex parameters, J. Affect. Disord. 82 (2004) 245–252.
[25] S.S. Bruce-Low, D. Cotterrell, G.E. Jones, Heart rate variability during high ambient heat exposure, Aviat. Space Environ. Med. 77 (2006) 915–920.
[26] R. Patterson, Human factors of 3-D displays, J. Soc. Inf. Disp. 15 (2007) 861–871.
[27] K. Matsumura, K. Miura, Y. Takata, H. Kurokawa, M. Kajiyama, I. Abe, M. Fujishima, Changes in blood pressure and heart rate variability during dental surgery, Am. J. Hypertens. 11 (1998) 1376–1380.
[28] J. Minami, M. Yoshii, M. Todoroki, T. Nishikimi, T. Ishimitsu, T. Fukunaga, H. Matsuoka, Effects of alcohol restriction on ambulatory blood pressure, heart rate, and heart rate variability in Japanese men, Am. J. Hypertens. 15 (2002) 125–129.
[29] M.V. Marrufo, E. Vaquero, M.J. Cardoso, C.M. Gómez, Temporal evolution of alpha and beta bands during visual spatial attention, Cogn. Brain Res. 12 (2001) 315–320.
[30] H. Oyamada, A. Iijima, A. Tanaka, K. Ukai, H. Toda, N. Sugita, M. Yoshizawa, T. Bando, A pilot study on pupillary and cardiovascular changes induced by stereoscopic video movies, J. NeuroEng. Rehabil. 4 (2007) 169–174.
[31] M.K. Lahiri, P.J. Kannankeril, J.J. Goldberger, Assessment of autonomic function in cardiovascular disease: physiological basis and prognostic implications, J. Am. Coll. Cardiol. 51 (2008) 1725–1733.
[32] R. Tabassum, N. Begum, S. Ferdousi, S. Begum, T. Ali, Heart rate variability in patients with essential hypertension, J. Bangladesh Soc. Physiol. 5 (2010) 169–174.
[33] P. Pavithran, R. Mithun, M. Jomal, H. Nandeesha, Heart rate variability in middle-aged men with new-onset hypertension, Ann. Noninvasive Electrocardiol. 13 (2008) 242–248.
[34] http://www.smh.com.au/news/entertainment/avatardeath/2010/01/19/1263663092281.html.

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