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Visual fatigue in Watching 3 Dimension Television

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Purpose: This study was to evaluate visual fatigue with passing of watching 3D TV in short term and with experience of watching 3DTV in long term. **Methods**: 98 adult subjects aged 33.5±5.5 years (22 to 51 years; 12 females and 86 males) agreed to participate in this study. Subjects were asked to watch 52 inch LED 2D and 3D television (Shutter glasses method) at 2.7 meters for 65minutes with wearing their habitual glasses or contact lenses. For evaluating visual fatigue, subjects were verbally responded to 11 questions : eye straining, eye paining, dry eye, sore eye, watery eye, photophobia, blur vision, diplopia, eye fatigue, headache, and dizziness with scale 0 to 3 at each measurement while watching 3D and 2D TV. **Results**: The mean scores of visual fatigue were 2.08± 2.14, 3.19±3.02, 3.40±3.37, 3.53±3.07 for after 5 minutes, 25 minutes, 45 minutes, and 65 minutes respectively for 3D TV, and 0.40±1.03, 0.22±0.70, 0.22±0.58, and 0.17±0.52 after 25, 45, and 65 minutes respectively for 2D TV. Visual fatigue for watching 3D TV was significantly higher than for watching 2D TV at all measurements sessions (paired t-test, $p < 0.001$). The visual fatigue significantly increased during watching 3D TV for 65 minutes ($p < 0.001$, RM-ANOVA). The visual fatigue during watching 3D TV was significantly increased until 25 minutes (paired t-test, $p < 0.001$), stable after that. For correlation between visual fatigue and 3D watching experience, the more 3D watching experiences were significantly the less visual fatigues in photophobia, blur vision, diplopic and dizzy symptoms (ANOVA, all $F(1, 96) = 4.500$, all $p < 0.05$), but there was not significantly different in the other symptoms (ANOVA, $F(1, 96) = 2.123$, $p = 0.148$). **Conclusions**: Visual fatigue for watching 3D TV was higher than for watching 2D TV, increase by 25 minutes. It was different by symptoms for correlation between visual fatigue and 3D watching experience.

Key words: Visual fatigue, Watching 3D TV, 3D TV watching experience

Introduction

3D refers to a three-dimensional (3D) image. The 3D image is produced by the perception of depth based on the difference between the two retinal images with binocular disparity. With differently with 2D TV, some viewers of 3D-TV perceive visual discomfort or visual fatigue. “Visual fatigue” is used interchangeably with “visual discomfort”, and refers to a decrease in the performance of the visual system as a consequence of physiological strain or stress resulting from excessive exertion[1]. Visual fatigue visual system change in watching 3D TV is very important for human factors. Peli (1998) compared monocular and stereoscopic head-mounted displays (HMD) and a regular CRT on potential harmful effects to visual system[2]. In his study, the binocular disparity values did not exceed one degree, implying that he remained within the accepted zone of comfortable viewing [1, 3-6]. Emoto, Nojiri and Okano (2004) evaluated changes within the visual system as a consequence of viewing still images for 60 minutes in monocular and stereoscopic mode and visual fatigue using a pre- and post-measurement of the fusion amplitude and the Accommodative Convergence/Accommodation ratio (AC/A ratio)[7]. They found that there were differences between the

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pre- and post-measurements of the AC/A ratio, but the fusion amplitude significantly decreased in the convergent direction after stereoscopic viewing. Emoto, Niida and Okana (2005) performed an experiment in which participants viewed films for almost one hour stereoscopically, monocularly, and in a simulated stereoscopic condition[7]. The simulated stereoscopic condition consisted of viewing monocular content through prisms. Prisms change the vergence, while keeping the accommodation constant. The strength of the prisms was set according to each participant's individual Percival's area of comfort, which describes the range of prism loads that does not induce any discomfort[2,8]. Both the accommodation response and the fusion amplitude were affected significantly by conditions with varying disparity in stereoscopic conditions, whereas the fusion amplitude also decreased significantly with fixed prism loads beyond as well as within Percival's area of comfort. Also no visual discomfort was perceived within Percival's area of comfort, which suggests that these changes in fusion amplitude indicated functional adaptations to altered viewing situations. From watching 3D TV, visual system will change to fix viewing stereoscopic content. The consequent visual complaints, which do not have to be present in normal viewing situations, may become present or more severe in unnatural viewing situations.

This study is to evaluate visual fatigue with passing of watching 3D TV time in short term and with experience of watching 3D TV in long term.

Subjects and Methods

98 adult subjects aged 33.5 ± 5.5 (mean ± SD) years (22 to 51 years; 12 females and 86 males) agreed to participate in this study once the risks and benefits of watching 3 dimension (D) and 2D TV had been explained. They were asked for 3D TV watching experience(times). Subjects were asked to watch 52 inch LED 3D television (Shutter glasses method) for 65minutes with wearing their habitual glasses or contact lenses. The watching distance kept 2.7 meters (2.5 times of diagonal measurement of screen size) to maximize the feeling of presence and thus provide a better viewing experience[9]. The contents of 3D TV were same with 2D contents. The order of watching was random order.

Visual fatigue was evaluated with scores, zero (no symptom), 1 (mild symptom), 2 (moderate symptom), or 3 (severe symptom), at 5 minutes and every 20 minutes. For evaluating visual fatigue, in-house questionnaire were used. Subjects were verbally responded to 11 questions at each measurement while watching 3D and 2D TV. The 11 questions are eye straining, eye paining, dry eye, sore eye, watery eye, photophobia, blur vision, diplopia, eye fatigue, headache, and dizziness.

The SPSS© statistical package (version 13.0) was used to analyze the data collected. Repeated measures analysis of variance (RM-ANOVA) was used to examine changes from 5 minutes watching 3D TV in visual fatigue over the study period. Changes from 5 minutes watching 3D TV in visual fatigue were examined using post-hoc paired Student t-tests with Bonferroni correction. In addition, relationship between visual fatigue and 3D watching experience was also examined using regression analysis. A critical p-value of 0.05 was chosen to denote statistical significance for all analyses.

Results

For watching 3D TV, the mean scores of visual fatigue of 11 questions were 2.08 ± 2.14, 3.19 ± 3.02, 3.40 ± 3.37, 3.53 ± 3.07 for after 5 minutes, 25 minutes, 45 minutes, and 65 minutes respectively. For watching 2D TV the mean scores of visual of 11 questions were 0.40 ± 1.03, 0.22 ± 0.70, 0.22 ± 0.58, and 0.17 ± 0.52 after 25, 45, and 65 minutes respectively (Fig. 1). Visual fatigue for watching 3D TV was significantly higher than for watching 2D TV at all measurements sessions (paired t-test, $p < 0.001$).

The visual fatigue significantly increased during watching 3D TV for 65 minutes ($p < 0.001$, RM-ANOVA). The

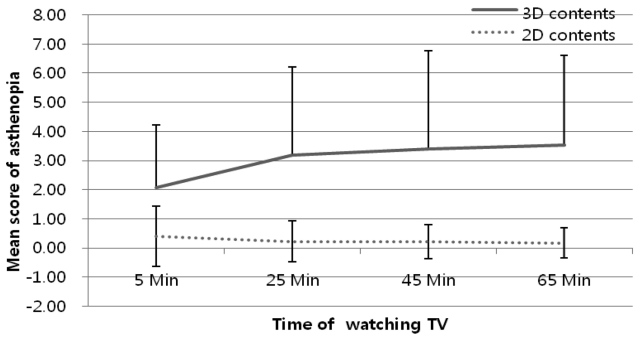

Fig. 1. Mean score of visual fatigue of 11 questions while watching 2D and 3D TV. Error bar represent standard deviations. Min = minute.

Table 1. Mean and standard deviations of the score of visual fatigue while watching 3D and 2D TV

Symptoms \ Watching time	TV Types	5 Minutes	25 Minutes	45 Minutes	65 Minutes
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Eye straining	3D	0.38 ± 0.57	0.50 ± 0.78	0.55 ± 0.79	0.48 ± 0.79
	2D	**0.04 ± 0.20**$^{+}$	**0.03 ± 0.17**$^{+}$	**0.02 ± 0.14**$^{+}$	**0.01 ± 0.10**$^{+}$
Eye pain	3D	0.13 ± 0.42	0.15 ± 0.48	0.20 ± 0.57	0.22 ± 0.58
	2D	0.03 ± 0.17	0.02 ± 0.14	**0.00 ± 0.00**$^{+}$	**0.00 ± 0.00**$^{+}$
Dry eye	3D	0.22 ± 0.49	**0.40 ± 0.60***	**0.45 ± 0.66***	**0.55 ± 0.75***
	2D	0.09 ± 0.29	**0.05 ± 0.22**$^{+}$	**0.05 ± 0.22**$^{+}$	**0.05 ± 0.22**$^{+}$
Sore eye(irritation)	3D	0.10 ± 0.34	0.20 ± 0.52	**0.28** ± 0.57*	**0.33** ± 0.64*
	2D	0.03 ± 0.17	**0.03 ± 0.17**$^{+}$	**0.02 ± 0.14**$^{+}$	**0.01 ± 0.10**$^{+}$
Watery eye	3D	0.03 ± 0.17	0.09 ± 0.29	0.13 ± 0.45	0.10 ± 0.34
	2D	0.00 ± 0.00	0.01 ± 0.10	0.01 ± 0.10	0.01 ± 0.10
Photophobia	3D	0.07 ± 0.30	0.09 ± 0.32	0.09 ± 0.32	0.05 ± 0.26
	2D	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Blur vision	3D	0.06 ± 0.28	0.09 ± 0.35	0.03 ± 0.22	0.03 ± 0.17
	2D	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Diplopia (double vision)	3D	0.48 ± 0.75	0.47 ± 0.80	0.34 ± 0.72	0.40 ± 0.85
	2D	**0.00 ± 0.00**$^{+}$	**0.00 ± 0.00**$^{+}$	**0.00 ± 0.00**$^{+}$	**0.00 ± 0.00**$^{+}$
Eye fatigue	3D	0.44 ± 0.72	**0.82** ± 0.78*	**0.99** ± 0.89*	**1.02*** ± 0.87
	2D	**0.14 ± 0.35**$^{+}$	**0.06 ± 0.24**$^{+}$	**0.10 ± 0.30**$^{+}$	**0.08 ± 0.28**$^{+}$
Headache	3D	0.09 ± 0.35	**0.20 ± 0.52***	0.21 ± 0.54	0.26 ± 0.61
	2D	0.06 ± 0.24	**0.02 ± 0.14**$^{+}$	**0.02 ± 0.14**$^{+}$	**0.01 ± 0.10**$^{+}$
Dizziness	3D	0.07 ± 0.30	0.17 ± 0.43	0.12 ± 0.33	0.09 ± 0.35
	2D	0.00 ± 0.00	**0.00 ± 0.00**$^{+}$	**0.00 ± 0.00**$^{+}$	0.00 ± 0.00

SD = Standard deviation,*= $p < 0.05$, Post-hoc paired Student t-tests versus 5 minute, $^{+}$ = $p < 0.05$, Post-hoc paired Student t-tests, watching 2D TV versus 3D TV.

visual fatigue during watching 3D TV significantly increased by 25 minutes (paired t-tests, $p < 0.001$), after that increased smoothly. There was no statistically significant changing of the visual fatigue during the 65 minutes of watching 2D TV (RM-ANOVA, $p = 0.060$).

Table 1 presents the mean score and standard deviations of visual fatigue of 11 questions during the study. The symptoms of dry eye, sore eye, eye fatigue, and headache were significantly increasing during the 65 minutes of watching 3D TV (RM-ANOVA, all $p \leq 0.036$). The increase of dry eye, sore eye, and eye fatigue symptoms was statistically significant by 25 minutes, 45 minutes, and 25 minutes of watching 3D TV respectively (paired t-tests, $p \leq 0.05$, $p < 0.05$, $p < 0.001$, respectively). The increase of the headache symptom was only statistically significant (paired t-test, $p < 0.05$) at 25 minutes of watching 3D TV. However there was no change in eye straining, eye staining, watery eye, photophobia, blur vision, diplopia and dizziness symptoms during watching 3D TV for 65 minutes (RM-ANOVA, all $p > 0.083$). There was also no change in eye straining, eye staining, dry eye, sore eye, watery eye, photophobia, blur vision, diplopia, eye fatigue, headache and dizziness symptoms during watching 2D TV for 65 minutes (RM-ANOVA, all $p = 0.074$).

The increase of eye straining, diplopia, and eye fatigue symptoms in watching 3D TV was significantly higher than in 2D TV during all measurements sessions (paired t-tests, all $p < 0.01$). The symptoms of dry eye, sore eye, and headache were significantly higher at 25 minutes, 45 minutes and 65 minutes with watching 3D TV than with

Table 2. Mean and standard deviations of the score of visual fatigue while watching 3D TV in different 3D watching experience

Symptoms \ Watching Experience	No Experience	10 Times	30 Times	50 Times	100 Times
Eye straining	0.0 ± 0.0	2.1 ± 2.8	1.4 ± 2.0	2.1 ± 2.9	2.0 ± 2.6
Eye pain	0.0 ± 0.0	0.9 ± 1.5	0.5 ± 1.8	0.4 ± 0.9	0.8 ± 2.2
Dry eye	1.0 ± 1.0	2.1 ± 2.2	1.3 ± 1.6	2.6 ± 2.4	1.1 ± 1.8
Sore eye (irritation)	0.3 ± 0.6	0.7 ± 1.4	0.8 ± 1.9	1.2 ± 1.9	1.0 ± 1.9
Watery eye	0.3 ± 0.6	0.4 ± 1.2	0.5 ± 1.2	0.3 ± 0.7	0.3 ± 0.7
Photophobia+	0.3 ± 0.6	0.4 ± 1.0	0.6 ± 1.2	0.5 ± 1.0	0.0 ± 0.2
Blur vision+	1.0 ± 1.7	0.4 ± 1.2	0.4 ± 0.8	0.0 ± 0.0	0.1 ± 0.3
Diplopia+ (double vision)	2.0 ± 2.6	3.1 ± 3.4	1.0 ± 1.6	1.1 ± 2.4	1.1 ± 2.6
Eye fatigue	2.0 ± 2.0	4.0 ± 2.9	2.1 ± 2.2	4.0 ± 2.9	3.0 ± 2.6
Headache	0.3 ± 0.6	0.7 ± 1.6	1.1 ± 1.4	0.7 ± 1.2	0.7 ± 2.2
Dizziness+	0.7 ± 1.2	0.7 ± 1.2	0.5 ± 1.2	0.5 ± 0.9	0.2 ± 0.8
Total	8.0 ± 8.0	15.6 ± 11.7	10.3 ± 12.3	13.3 ± 6.6	10.4 ± 9.9

SD = Standard deviation, +: $p < 0.05$, Regression analysis.

watching 2D TV (paired t-tests, all $p < 0.05$). The eye staining was significantly higher at 45 minutes and 65 minutes (paired t-tests, $p < 0.05$, $p < 0.01$, respectively), the dizziness was significantly higher at 25 minutes and 45 minutes (paired t-tests, $p < 0.01$, $p < 0.05$, respectively) in watching 3D TV than 2D TV. However there was no significantly different symptoms in watery eye, photophobia, and blur vision between watching 3D TV and 2D TV at all measurements sessions.

Table 2 presents the mean score and standard of visual fatigue of 11 questions in different 3D watching experience. There was no relationship between 3D watching experience and visual fatigues in eye straining, eye pain, dry eye, sore eye, watery eye, eye fatigue and headache symptoms (AVOVA, all $F(1,96) = 0.033$, all $p > 0.05$), and visual fatigues in all 11 symptoms (ANOVA, $F(1, 96) = 2.123$, $p > 0.05$). However the more 3D watching experiences were significantly the less visual fatigues in photophobia, blur vision, diplopic and dizzy symptoms (ANOVA, all $F(1, 96) = 4.500$, all $p < 0.05$)

Discussion

Human eyes are horizontally separated, each eye has its own perspective of the world, and thus both eyes receive slightly different images. Stereopsis is the perception of depth that is constructed based on the difference between these two retinal images. The brain fuses the left and right images from retinal disparity, and the brain extracts relative depth information[1]. The principle of stereopsis perception in watching 3D TV is same as the principle in viewing real world. However, the difference between 3D TV and real world to produce stereopsis is that 3D TV needs two images for right and left eyes, on the other hand, real world need simultaneously one real object for two eyes. Therefore, for stereopsis perception during watching 3D TV, our eyes are required a different visual mechanism to viewing real world. This different visual mechanism may cause that visual fatigue in watching 3D TV was significantly higher than in watching 2D TV due to difference visual mechanism between in watching 3D and 2D images[10-13].

In the course of visual fatigue during watching 3D TV, our results showed that visual fatigue increased by 25 minutes, after that increased smoothly. Eadie et al. revealed that stereoscopic stimuli can initiate changes in the cross-link interaction between vergence and accommodation which are altered AC/A, CA/C ratios, and in the tonic components[10]. These changes can have negative consequences for clear and single binocular vision, because changes in the optical alignment of the eyes affect binocular fusion limits and depth perception[14-15]. The visual system has some degree of plasticity and is able to adapt to altered

viewing conditions. Such alterations may last minutes or even hours, because re-adaptation to the real world is needed[16]. Our results showed that mean of symptoms changed more quickly until 25 minutes than the later of 25 minutes but all symptoms did not equal changes in passing of 3D watching time in terms of short time watching 3D TV. Among the symptoms, eye fatigue stably increased. This may occur by accumulate of visual fatigue with passing of watching 3D TV. In experience of 3D TV watching our results showed that the more increase of watching time was significantly the less visual fatigue in photophobia, blur vision, diplopic and dizzy symptoms. However it was not significantly different in other symptoms. These results may be that it is difficult for subjects exactly to evaluate subject symptoms[17]. Nevertheless some symptoms were significantly reduced with 3D watching experience. This result seems from that visual system has some degree of plasticity and is able to adapt to altered viewing conditions in long terms[18].

Therefore, it is expected that even visual fatigue has a tendency to increase in short time watching, it will decrease in some symptoms with experiences of watching 3D TV in long terms.

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3D TV 시청에 있어서 시청 피로

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목적: 본 연구는 장시간 3D TV 시청 경험과 단시간 TV 시청 경과에 따른 시청피로를 평가하기 위함이다. **방법**: 98명의 성인(여자12 명과 남자86명)으로 실시하였으며, 이들의 나이는 33.5±5.5세(22세~51세)였다. 대상자는 52인치 2D와 3D LED TV(shutter glasses 방식)를 2.7 m 거리에서 대상자가 주로 착용하는 안경 또는 콘택트렌즈를 착용한 상태에서 65분간 2D TV와 3D TV를 각각 시청하게 하였다. 시청피로도 평가를 위해 3D와 2D를 시청하는 동안 11개 항목, 눈의 당김, 눈의 통증, 눈건조, 눈의 따끔거림, 눈물, 눈부심, 흐림, 복시, 눈피로, 두통, 어지럼 등을 0에서 3의 점수로 평가하였다. **결과**: 시청피로의 평균점수는 3D 시청시작 후 5분, 25분, 45분, 65분에서 각각 2.08±2.14, 3.19±3.02, 3.40±3.37, 3.53±3.07으로 나타났고, 2D 시청 시작 후는 각각0.40±1.03, 0.22±0.70, 0.22±0.58, 그리고 0.17±0.52으로 나타났다. 3D TV 시청 시 시청피로가 2D TV 시청 시 피로 보다 전체 영역에서 유의적인 수준에서 높게 나타났다(paired t-test, $p < 0.001$). 3D TV 시청 피로는 65분간 유의적인 수준에서 증가하였으며(RM-ANOVA, $p < 0.001$), 25분까지는 유의적 수준에서 증가하였고(paired t-test, $p < 0.001$), 그 후부터 서서히 증가하였다. 시청경험과 시청피로에 있어서 눈부심, 복시, 흐림, 어지럼은 시청 경험의 증가할수록 감소하였으나(ANOVA, all $F(1, 96) = 4.500$, all $p < 0.05$) 다른 증상에 있어서는 유의한 차이가 없었다($F(1,96) = 0.033$, all $p > 0.05$) **결론**: 3D TV 시청에 있어서 시청피로는 2D에서 보다 높았으며, 25분까지 증가하였다. 3D 시청 경험과 자각증상 정도와의 관계에 있어서는 자각증상에 따라 다르게 나타났다.

주제어: 시청 피로, 3D TV 시청, 3D TV 시청 경험