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Effects of Viewing Angle of Stereoscopic Images on Heterophoria and Accommodation

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Abstract

This study attempted to evaluate the impacts of viewing angle in watching stereoscopic images on heterophoria and accommodation. It divided students in one college located in Gumi City, who agreed to participate in this study, into two groups for classification by solid angle, horizontal heterophoria and accommodation before viewing, after 2D viewing and 3D viewing were measured.

*As a result of the study, long distance horizontal heterophoria increased to exophoria after watching 3D images in both groups that watched them at a solid angle of 0.23*sr *and 0.10sr (p<0.05), and short distance horizontal heterophoria increased to exophoria in the group that watched the images at 0.23*sr *after watching 2D images and 3D images, and exophoria significantly increased in the group that watched them at 0.10*sr *after watching 3D images. Changes in positive relative accommodation after watching 2D images and 3D images significantly decreased with changes in solid angle (p<0.05). Changes in negative relative accommodation were not statistically significant after watching 2D images and 3D images according to solid angle.*

*The relevance of viewing angle of 3D images with horizontal heterophoria and accommodation had statistically significant differences (*p*<0.05).*

Keywords*: 2D images, 3D images, heterophoria, Accommodation, Solid angle*

1. Introduction

Global market research firm, NPD Display Search forecasted through a 3D display technology and a market forecast report that by the end of 2011, the global 3D display market scale would be $13.2 billion and a sales volume of 50,800,000 units. In addition, by 2019, the 3D display market scale would be $67 billion and increase to a sales volume of 226 million (*Display Search*, 2010). The development of 3D display technology has achieved rapid development in the video market, getting the limelight as a next generation broadcasting technology. However, problems of photosensitivity, image motion sickness and visual fatigue, according to watching 3DTV come to the fore, which are the problems that must be solved in advance for the development of the 3D industry [1].

When the eyes look at a random object, synkinetic eye movement causes control, convergence and miosis. Convergence and miosis occur by a stimulus at a certain distance, and in watching 3D images, due to backward and forward of the images, mismatch of control and convergence occurs, which causes eye fatigue [1,2,3].

The principle of forming a cubic effect is that the image formed individually on both eyes moves through the optic nerve and is finally fused as one image in the brain's visual cortex, and the difference in the fine image between the two eyes occurring at this time produces a stereoscopic effect. At this time, the difference between the images apart from the fusion scope is not fused into one, but appears as diplopia. In addition, when the difference between images of the two eyes is on the boundary of the fusion scope, a viewing struggle occurs, which causes visual fatigue [4, 5].

To give a great cubic effect in 3D images, the degree of the separation between two im-

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ages should be enlarged, and if this degree of separation goes out of the viewer's range of fusion, it is perceived as diplopia, which causes discomfort and asthenopia.

International Standard Organization (ISO) presented a few guidelines related to the safety of images in 2005, and the issue of the safety of images includes photosensitivity, motion sickness and visual fatigue, so the issue of body safety is emphasized [6], and 3D Consortium presents recommendations for display and specifications of LCD shutter glasses and concrete guidelines for to prevent visual fatigue such as based on the materials of the ISO (IWA3) [7].

In South Korea, Korea Communications Commission organized and operated 3D viewing safety conference since May 2010 and carried out full studies and discussions about the safety of 3D images.

An actual study was conducted on the five basic items of 3D viewing in 2010 (viewing distance, viewing time, viewing angle, interpupillary distance and motion sickness sensitivity), and summing up 3D viewing safety-related existing study literature research and medical findings, it published a clinical proposal of recommendation (Ver. 1.0) on the safety of 3D images in December 2010, and a revised clinical proposal of recommendation (Ver.3.0) on the safety of 3D images in December 2012 [8].

Like this, fatigue generated in watching contents presented through a 3D display includes visual fatigue, such as eye pain and double image experience, is accompanied by headache, motion sickness and dizziness symptom, and in severe cases, causes vomiting, and this phenomenon is called 3D fatigue [9].

Thus, in order to minimize this inconvenience, various studies have been carried out in the field of human factors related to the method of implementing 3D images or graphic related display field and visual function [10,11,12].

Till now, as studies to investigate the cause of physical, visual symptoms caused by 3D images, studies on subjective visual symptoms have been conducted, but actually, studies carried out based on the solid angle measured in the actual viewing are very limited.

This study observed 3DTV broadcasting safety guidelines and carried out a test on horizontal heterophoria and accommodation based on the solid angle in watching 3D images and evaluated the impacts of watching 3D images on heterophoria and accommodation according to the solid angle.

This study will use its results as the materials as plans to establish guidelines for watching 3DTV and solve and cope with the extraordinary reaction of 3D viewing.

2. Research Method

2. 1. Research Subjects

From December 2012 to April 2013, eighty students with the corrective vision of 0.8 or above, attending one undergraduate school in Gumi, Gyeongsangbukdo and being able to watch 3D, completed the horizontal heterophoria and Accommodation test. All subjects were divided into two groups, except for 4 subjects who failed to pass the suppression test, and 40 subjects were assigned to the group A and 36 subjects to the group B.

2. 2. Research Methods

Subjects participating in the experiment were diagnosed by asking questions about their general health status and eye fatigability before watching images to inspect the elements that might affect the experiment, after which, they participated in the experiment under the same conditions.

A horizontal heterophoria test (von Grafe method), positive relative accommodation (PRA), negative relative accommodation (NRA) test were conducted.

The intensity of illumination in the laboratory was maintained at 130-215 lx and the intensity of illumination in the ocular surface was maintained at 800-1,000 lx [13]. Prior to watching images, tests were conducted on horizontal heterophoria and accommodation, and tests were conducted again after watching 2D images and 3D images.

While watching each image, they were asked to view with a single method a day so that fatigability by viewing would not have an impact, and participate in the experiment after taking a sufficient rest.

The time of watching images was 30 minutes when the viewing fatigue becomes the maximum value, and the test was completed within 10 minutes [14]. As the images used in the experiment, the film [15,16] 'Avatar (U.S.A., 2009)' was selected among concerts, theaters, sports and action movies, appropriate genres for 3D images, and they watched the image 1 to 4 p.m. when the visual function would be the most stable, and the same sections were used for 2D images and 3D images.

The method of viewing was based on 3DTV broadcasting safety guidelines [17,18]. The standard viewing distance was 3 to 6 times the vertical length of the display, and Group A viewed the images 1m away from the display, the standard viewing distance of 32-inch display while the viewing distance of Group B was fixed at 3m, the standard viewing distance of 55-inch display.

Subjects were required to watch 3D with the standard of a solid angle, and the solid angle is defined as the two-dimensional angle in three dimensional space that an object subtends at a point and its equation is (1). Upon categorization by solid angle, the group A is 0.23 *sr* and the group B is 0.10 *sr* [19].

The data analysis was done with SPSS ver. 20.0, and survey questionnaires and data collected before watching and after watching 2D and 3D were compared in graphs and tables by using the paired t-test, independent t-test and ANCOVA. ANCOVA handled a result of the visual performance inspection test before watching as covariate. When $p<0.05$, it was considered as statistically significant.

$$\text{Solid angle} = S/r^2 \ [sr] \quad (1)$$

S = Square [m2], r = range [m], sr = steradian

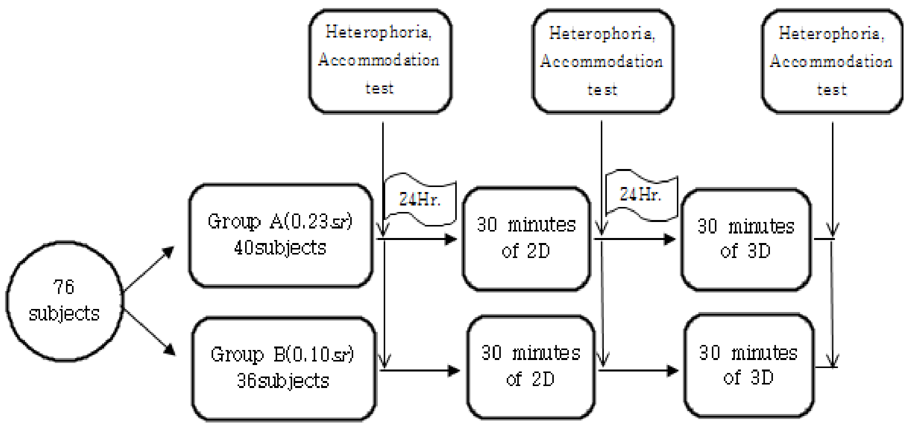

Figure 1. Process

3. Results

3. 1. Change in Far-Distance Horizontal Heterophoria

The group that watched images at a solid angle of 0.23 *sr* had an increase in the far-distance horizontal heterophoria as exphoria after watching 2D (-2.36±2.50) than before watching (-2.21±2.11), but not significant. Also, there was a significant increase in the far-distance horizontal heterophoria as exphoria after watching 3D (-2.74±2.64) than before watching 3D (-2.21±2.11) ($p<0.05$).

The group that watched images at a solid angle of 0.10 *sr* had a significant increase in the far-distance horizontal heterophoria as exphoria after watching 2D (-1.55±0.85) than before watching 2D (-1.91±1.06) ($p<0.05$). Also, there was a significant increase in the far-distance horizontal heterophoria as exphoria after watching 3D (-1.55±0.85) than before watching 3D (-2.47±1.23) ($p<0.05$) (Table 1).

Table 1. Change in Far-Distance Horizontal Heterophoria after Watching 2D and 3D upon Solid Angle

Solid angle (*sr*)	Before watching	After watching 2D			After watching 3D		
	M±SD	M±SD	$p^{1)}$	$p^{2)}$	M±SD	$p^{3)}$	$p^{4)}$
0.23	-2.21±2.11	-2.36±2.50	0.460	0.267	-2.74±2.64	0.023	0.90
0.10	-1.55±0.85	-1.91±1.06	0.005		-2.47±1.23	0.000	
$p^{5)}$	0.06	0.371			0.614		

Unit : ∆ (Prism)
Phoria : + Esophoria , - Exophoria
$p^{1)}$: Paired t-test (Before watching – After watching 2D) $p^{2)}$: ANCOVA (Before watching – After watching 2D)
$p^{3)}$: Paired t-test (Before watching – After watching 3D) $p^{4)}$: ANCOVA (Before watching – After watching 3D)
$p^{5)}$: Independent t-test

3. 2. Change in Near-Distance Horizontal Heterophoria

The group that watched images at a solid angle of 0.23 *sr* was shown to have a significant increase in the near-distance horizontal heterophoria as exphoria both after watching 2D (-7.03±4.77) and 3D (-7.94±4.89) than before watching (-6.43±4.52) ($p<0.05$).

The group that watched images at a solid angle of 0.10 *sr* was shown to have a significant increase in the near-distance horizontal heterophoria as exphoria after watching 3D (-8.64±3.36) than before watching (-10.11±3.22) ($p<0.05$). Even though it was shown that there was a significant increase in the near-distance horizontal heterophoria as exphoria by a solid angle ($p^{5)}=0.046$), there was no significant change in a result of ANCOVA (Table 2).

Table 2. Change in Near-Distance Horizontal Heterophoria after Watching 2D and 3D upon Solid Angle

Solid angle (*sr*)	Before watching	After watching 2D			After watching 3D		
	M±SD	M±SD	$p^{1)}$	$p^{2)}$	M±SD	$p^{3)}$	$p^{4)}$
0.23	-6.43±4.52	-7.03±4.77	0.001	0.747	-7.94±4.89	0.000	0.447
0.10	-8.64±3.36	-9.10±3.64	0.149		-10.11±3.22	0.004	
$p^{5)}$	0.06	0.066			0.046		

Unit : ∆ (Prism)
Phoria : + Esophoria , - Exophoria
$p^{1)}$: Paired t-test (Before watching – After watching 2D) $p^{2)}$: ANCOVA (Before watching – After watching 2D)
$p^{3)}$: Paired t-test (Before watching – After watching 3D) $p^{4)}$: ANCOVA (Before watching – After watching 3D)
$p^{5)}$: Independent t-test

3. 3. Change in Positive Relative Accommodation

In the group watching images at 0.23 sr, positive relative accommodation tended to increase somewhat after watching 2D images (-2.88±1.60) and 3D images (-2.83±1.47) from that before watching them (-2.69±1.52), but there was no statistically significant difference.

In the group watching images at 0.10 sr, positive relative accommodation did not have any statistically significant changes before watching images (-2.22±0.63) and after watching 2D images (-2.17±0.76) and 3D images (-2.30±0.82).

The change in the positive relative accommodation after watching 2D images significantly decreased as the solid angle changed from 0.23 sr to 0.10 sr (p value[5])=0.02).

The change in the positive relative accommodation after watching 3D images significantly decreased as the solid angle changed from 0.23 sr to 0.10 sr (pvalue[5])=0.04) (Table 3).

Table 3. Change in Positive Relative Accommodation after Watching 2D and 3D upon Solid Angle

Solid angle (*sr*)	Before watching	After watching 2D			After watching 3D		
	M±SD	M±SD	p[1])	p[2])	M±SD	p[3])	p[4])
0.23	-2.69±1.52	-2.88±1.60	0.197	0.111	-2.83±1.47	0.236	0.280
0.10	-2.22±0.63	-2.17±0.76	0.741		-2.30±0.82	0.769	
p[5])	0.09	0.02			0.04		

Unit : Δ (Prism)
Phoria : + Esophoria , - Exophoria
p[1]): Paired t-test (Before watching – After watching 2D) p[2]): ANCOVA (Before watching – After watching 2D)
p[3]): Paired t-test (Before watching – After watching 3D) p[4]): ANCOVA (Before watching – After watching 3D)
p[5]): Independent t-test

3. 4. Change in Negative Relative Accommodation

In the group watching images at a solid angle of 0.23 *sr*, negative relative accommodation did not have any statistically significant change after watching 2D images (2.38±0.52) and 3D images (2.40±0.48) from that before watching them (2.41±0.51).

Also, in the group watching images at a solid angle of 0.10 *sr*, negative relative accommodation did not have any statistically significant change before watching images (2.42±0.60) and after watching 2D images (2.52±0.71) and 3D images (2.49±0.66).

The change in the negative relative accommodation was not statistically significant after watching 2D images and 3D images according to the solid angle(Table 4).

Table 4. Change in Negative Relative Accommodation after Watching 2D and 3D upon Solid Angle

Solid angle (*sr*)	Before watching	After watching 2D			After watching 3D		
	M±SD	M±SD	p[1])	p[2])	M±SD	p[3])	p[4])
0.23	2.41±0.51	2.38±0.52	0.590	0.090	2.40±0.48	0.921	0.286
0.10	2.42±0.60	2.52±0.71	0.113		2.49±0.66	0.243	
p[5])	0.93	0.23			0.42		

Unit : Δ (Prism)
Phoria : + Esophoria , - Exophoria
p[1]): Paired t-test (Before watching – After watching 2D) p[2]): ANCOVA (Before watching – After watching 2D)
p[3]): Paired t-test (Before watching – After watching 3D) p[4]): ANCOVA (Before watching – After watching 3D)
p[5]): Independent t-test

4. Discussion

Recently, with the development of video technologies and the digitization of movie theaters, the distribution of 3D movies has already been vitalized from the film Avatar, and with the effort to spread it to households, the service of 3DTV contents has already been realized by the digitization of broadcasting in some broadcasting. Accordingly, an interest in the impact of watching 3D images on human body increased.

This study analyzes visual functions through a comparison before and after watching 2D and 3D images according to the solid angle among the methods of watching presented by the clinical proposal of recommendation for the safety of 3D images to evaluate health effects and use it to prepare guidelines for watching 3D images and present an alternative according to them.

The clinical proposal of recommendation for the safety of 3D images (2012) suggested that youths aged 7 through 19 sensitively react to the light stimulus of 3D contents and recommended that they should refrain from excessive watching them in a state of fatigue, so the subjects of this study selected persons over 20 [8].

3D images cannot mostly be observed from all positions, but only when observers are located in a specific scope, they can observe right 3D images. Thus, based on the central axis of 3D images, the maximum angle from which the observers can observe 3D images was defined as a viewing angle [20], and a solid angle is defined as three-dimensional angle when they viewed a certain curved surface from a single point [21], which is an expansion of a two-dimensional angle to a three-dimensional one.

Bergquist et al. [22], reported that watching the display screen caused a phenomenon of asthenopia by the eyes and eye muscles' excessive tension, and in this study, also, the subjects complained of discomfort after watching 2D images. There was more asthenopia after watching 3D images than after watching 2D images, and this symptom was consistent with Ames et al.[12] and Wook-Jin Lee et al. [23].

In the visual function data, regarding the change in long distance horizontal heterophoria, there was an increase to exophoria after watching 3D images as compared to that before watching them at a solid angle of 0.23 *sr*, and there was an increase in exophoria after watching 2D images as compared to that before watching them in the group watching them at a solid angle of 0.10 *sr*. This trend was consistent with Richer et al. [24] that exophoria was caused after watching the display and Ukai [25] that exophoria was caused after watching 3D images.

2D images cause convergence within horizontal vergence to a regular control, but in watching 3D images, the process of fusing images separated in accommodation of viewing distance into one causes converge outside the range of horizontal vergence, and in this process, it tends to become exophoria by asthenopia due to the collision between control and convergence.

Regarding the change in short distance horizontal heterophoria, exophoria increased after watching 3D images than that before watching the 3D images in the group watching them at a solid angle of 0.10 *sr*. Regarding this factor, it is interpreted that fusion stimulus involved in watching 3D images rather than in watching 2D images acted as a greater fatigue factor on the eyes.

The change in short distance horizontal heterophoria after watching 2D images according to the solid angle increased to exophoria as a result of an independence t-test while it did not increase in the result of a covariance analysis. The change in short distance horizontal heterophoria after watching 3D images, also, increased to exophoria in the result of the independence t-test while it did not increase in the result of the covariance analysis. This is because there were differences after watching general images and 3D images according to the solid angle as a result of the independence t-test, but the difference after watching in the result of the covariance analysis was caused by the difference in visual functions before watching, the covariance, rather than the difference in the solid angle.

In the relative accommodation, there were no significant differences before and after watching 2D and 3D images in positive relative accommodation and negative relative accommodation. While the positive relative accommodation decreased in the result of an independence t-test after watching 2D and 3D images according to the solid angle, in the result of a covariance analysis, there was no significant decrease. This is because there were differences after watching 2D and 3D images according to the solid angle as a result of the independence t-test while the differences after watching them as a result of the covariance analysis was mainly caused by the differences in the relative accommodation before watching, the covariance, rather than the differences in the solid angle.

In Ukai et al. and Sumio et al. [26], also, it turned out that negative relative accommodation decreased in the group with instability in watching after watching 3D images and that the decrease tended to be larger in watching 3D images than watching 2D images due to the visual fatigue.

5. Conclusions

This study attempted to evaluate the impacts of watching 3D images on the human body through tests on horizontal heterophoria and accommodation. In particular, there have been few studies of tests on heterophoria and accommodation using the solid angle, following guidelines for the safety of 3DTV broadcasting. The results of this study will be used as materials establishing guidelines for watching 3D images and presenting another alternative.

The limitations of this study include that the average age of the subjects was 22.5 years old, which was confined to the young generations, that the number of subjects was 40 and 36 persons per group, that there are many myopic patients and exophoria patients, so that it is difficult to generalize the results of the study.

It is hopeful that this study will be used for the verification of the items of guidelines for the safety of watching images and as a material of a clinical proposal of recommendation, and through an analysis of additional visual functions, it should be added that there are impacts of the state of the individual viewer's visual functions and a difference in asthenopia in watching 3D images.

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References

[1] D.M. Hoffman, A.R. Girshick, K. Akeley, M.S. Banks, “Vergence accommodation conflicts hinder visual performance and cause visual fatigue”, J Vision, vol. 8, no. 3, **(2008)**, pp. 1-30
[2] Howarth, A. Peter, “Potential hazards of viewing 3-D stereoscopic television, cinema and computer games: a review”, Ophthalmic and Physiological Optics, vol. 31, no. 2, **(2011)**, pp. 111-122
[3] K. Dakashi, M. Hiroyuki, O. Keiji and A. Nobuaki, “Stereoscopic 3D representation of the basic”, Seoul, **(2011)**.
[4] P. E. Romano, J. A. Romano, and J. E. Puklin. “Stereoacuity development in children with normal binocular single vision”, Am J Ophthalmol, vol. 79, no. 6, **(1975)**, pp. 966-971.
[5] V. Noorden, G. K., “Binocular Vision and Ocular Motility: Theory and Management of Strabismus.” Mosby, St Louis, **(1996)**.
[6] IWA, ISO. "Image safety: Reducing the incidence of undesirable biomedical effects caused by visual image sequence", **(2005)**.
[7] 3D Consortium, "3DC Safety Guidelines for Popularization of Human-friendly 3D", **(2006)**.
[8] 3D images safety association. Practical recommendation for 3D images safety, **(2012)**.
[9] S. I. Park, M. C. Whang, J. W. Kim, S. C. Mun and S. M. Ahn, “Autonomic Nervous System response affected by 3D visual fatigue evoked during watching 3D TV”, Journal of Emotional Science, vol.14, no. 4, **(2011)**, pp. 653-662
[10] A. Oohira, and M. Ochaiai, "Influence on visual function by a stereoscopic TV programme with binocular liquid crystal shutter and Hi-Vision TV display", Ergonomics, vol. 39, no. 11, **(1996)**, pp. 1310-1314.
[11] S. Nichols, "Physical ergonomics of virtual environment use", Applied Ergonomics, vol. 30, no. 1, **(1999)**, pp. 79-90.
[12] S. L. Ames, J. S. Wolffsohn, and N. A. Mcbrien, "The development of a symptom questionnaire for assessing virtual reality viewing using a head-mounted display", Optometry & Vision Science, vol. 82, no. 3, **(2005)**, pp. 168-176
[13] J. D. Kim. “Clinical optometry and visual function prescription”, Seoul, **(2010)**.
[14] P. J. Sung, “Optometry”, Seoul, **(2011)**.
[15] J. Freeman, and S. E. Avons, "Focus group exploration of presence through advanced broadcast services", Proceedings-SPIE The International Society for Optical Engineering, International Society for Optical Engineering, **(2000)**.
[16] W. IJsselsteijn, *et al.*, "Effects of stereoscopic presentation, image motion, and screen size on subjective and objective corroborative measures of presence", Presence, vol.10, no. 3, **(2001)**, pp. 298-311.

[17] C. H. Lee. “Human Factor Research on the Measurement of Subjective Three Dimensional Fatigue”, broadcast engineering, vol. 15, no. 5, **(2010)**, pp. 607-616
[18] M. Sugawara, "Future Prospects of HDTV--Technical Trends Toward 1080p", SMPTE motion imaging journal, vol. 115, no. 1, **(2006)**, pp. 10.
[19] J. H. Kang, S. C. Park and J. S. Son. “The Effect of View Angle of Stereoscopic image on Heterophoria”, Advanced Science and Technology Letters, SERSC, vol. 61, pp.89-93.
[20] Dictionary of IT, “Telecommunications Technology Association”, **(2006)**.
[21] D. H. Kim. “Dictionary of Electric”, Seoul, **(2011)**.
[22] U. Bergquist and B. G. Knave, "Eye Discomfort and Work With Visual Display Terminals", Journal of Safety Research, vol. 26, no. 2, **(1995)**, pp. 126-127.
[23] W. J. Lee, “Self-Reported Symptoms and Stereopsis in Viewing 2D and 3D Images”, J. Korean Oph. Opt. Soc., vol. 16, no. 1, **(2011)**, pp. 83-90.
[24] H. Richter and O. Franzen, “Reduction of visual discomfort (asthenopia) & phoria following modulation of VDT nearwork induced accommodative hysteresis”, J. Behavioral Optometry, vol. 13, no. 5, **(2002)**, pp 119-112.
[25] K. Ukai, "Human Factors for Stereoscopic Images", ICME, **(2006)**, pp. 1697-1700.
[26] Y. Sumio “Visual perception from stereoscopic images for system design”, Global 3D technology forum. Korea chamber of conferce & industry, **(2011)**.

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