ISSN(print) 1226-5012
J Korean Ophthalmic Opt Soc. 19(3):363-369, September 2014 http://dx.doi.org/10.14479/jkoos.2014.19.3.363

Binocular Vision Corrective Spectacle Lenses Reduce Visual Fatigue in 3-D Television Viewing

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(Received August 1, 2014: Revised September 2, 2014: Accepted September 18, 2014)

Purpose: Three-dimensional (3D) displays are very useful in many fields, but induce physical discomforts in some people. This study is to assess symptom type and severity of asthenopia with their habitual distance corrective spectacle (HDCS) and their binocular vision corrective spectacle lenses (BVCSL) in people who feel physical discomforts. **Methods:** 35 adult subjects (ages 32.2±4.4 yrs) were pre-screened out of 98 individuals to have the highest symptom/asthenopia scores following 65 minutes of 3D television viewing with HDCS. These 35 individuals were then retested symptom/asthenopia scores during they watched 3D television for 65 minutes at a distance of 2.7 m with wearing BVCSL of horizontal, vertical or base down yoked prisms. A 4-point symptom-rating scale questionnaire (0=no symptom and 3=severe) was used to assess 11 symptoms (e.g., blur, diplopia, etc.) related to visual fatigue/visual discomfort. Distance and near lateral phoria were measured using Howell phoria card and vertical phoria were measured using Maddox rod. Symptoms induced by watching 3D TV were compared between wearing HDCS and BVCSL. **Results:** Asthenopia in watching 3D TV with wearing BVCS was significantly lower than wearing HDCS at 5, 25, 45, and 65 minutes (all $p < 0.001$, paired t-tests). In only refractive error power correction power group, all asthenopia was not significantly different between HDCS and BVCSL (all $p \geq 0.05$, paired t-tests). In prism correction groups for binocular imbalance, symptoms of asthenopia, however, was significantly lower for when wearing BVCSL than when wearing HDCS (all $p < 0.05$). **Conclusions:** Correction of phoria/vergence-based binocular vision imbalance can reduce asthenopia during 3D television viewing. An individual with binocular vision imbalance need corrected/compensated glasses with appropriate prisms prior to prolonged viewing of 3D television displays to reduce asthenopia/visual fatigue.

Key words: 3D television, Asthenopia, Binocular vision imbalance, Phoria

INTRODUCTION

Three-dimensional (3D) displays are very useful in many applications including vision research, operation of remote devices, medical imaging, scientific visualization, and various educations. Unfortunately, 3D displays often yield distortions in perceived 3D structure compared with the percepts of the real scenes the displays depict, and induce physical discomforts in some people.[1-3] Viewing symptoms such as asthenopia, blurred vision and double vision were associated the mismatching vergence and accommodative demands occurred in S3D viewing.[4-7] Differently with viewing real images, mismatching between those two components arises from a significant difference in the stimulus to vergence decided by image disparity relative to accommodation decided by the focal depth of S3D display.[8,9] Visual comfort can also be affected not only mismatching vergence and accommodation but also by the angle of gaze, relative to the primary horizontal gaze position, imposed by the position of the screens. Asthenopia, ocular fatigue or discomfort also appear to be the symptoms most often associated with binocular disorder under normal viewing condition.[10] Near exophoria with vertical phoria and lower vertical fusion reserve can be causes of asthenopia.[11]

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Even there have been many studies to evaluate fatigues of 3D viewing, the studies to reduce fatigues in 3D viewing are not easily found. Hoffman *et al*.[12] reported that when focus cues are correct or nearly correct, the time required to identify a stereoscopic stimulus is reduced, stereo acuity in a time-limited task is increased, distortions in perceived depth are reduced, and viewer fatigue and discomfort are reduced. However, this result is also not sufficient to use as a method to reduce fatigue in 3D viewing.

As result of previous studies, components to induce asthenopia in both real and 3D viewing can be mismatching accommodation and vergence, or/and binocular vision dysfunctions, which can be corrected by glasses with prism. So we try to reduce uncomfortable or asthenopia of 3D viewing by glasses correction with resolving mismatching accommodation and vergence. This study is to assess symptom type and severity with and without their binocular vision corrective spectacle lenses (BVCSL).

SUBJECTS AND METHODS

35 adult subjects (ages 32.2±4.4 yrs) were pre-screened out of 98 individuals to have the highest symptom/asthenopia scores following 65 minutes of 3D television viewing with their habitual distance spectacle correction. They did not have amblyopia, strabismus, or ocular disease. These 35 individuals were then retested as they watched 3D television for 65 minutes at a distance of 2.7 m (which reduced the mismatch between accommodation and vergence). Retesting was conducted in a counterbalanced manner with either their habitual distance corrective spectacles (HDCS) or their BVCSL; the latter corrected/compensated for their exophoria with base-in prisms, their esophoria with base-out prisms (combined with 0.75 D yoked prisms), and their vertical phoria with vertical prisms. Time separation between the HDCS and BVCS retesting conditions was over couple of days for adaption to BVCSL. Objective refractive errors were measured with Vision-K 5500 (Shinnippon, Japan). Distance and near lateral phoria were measured using Howell phoria card and vertical phoria were measured using Maddox rod. Distance and near fusion reserve were measured using prism bar (Luneau Ophthal, France). Subjects were verbally responded to 11 questions at each measurement while watching 3D. The 11 questions were eye straining, eye pain, dry eye, sore eye (irritation), watery eye, photophobia, blur vision, diplopia (cross-talk), eye fatigue, headache and dizziness

A 4-point symptom-rating scale questionnaire (0=no symptom and 3=severe) was used to assess 11 symptoms (e.g., blur, diplopia, etc.) related to visual fatigue/visual discomfort. It was administered at 4 equal intervals during each 65 minute test session.

The subjects were divided into 4 groups by type of prescribed prism lens for managing binocular dysfunction. The 4 groups were a group of correction power without prism(CP), base-in prism (BIP) group, vertical prism (VP) group and base-down yoked prism (BDYP) group. Base-in prism, and base-in and vertical prism were included for the BIP group, vertical prism, vertical and base-in prism, and vertical prism and base down yoked prism for the VP group, base-down yoked prism, base-down yoked and base-in prism, and base-down yoked and vertical prism for the BDYP group.

The SPSS statistical package (version 13.0) was used to analyse the data collected. Repeated Measures Analysis of Variance (RM-ANOVA) was used to examine changes over the study period. Changes from 5 minutes 3D TV watching were examined using posthoc paired student t-tests with Bonferroni correction. Paired-samples t-test was used to examine changes from wearing their habitual spectacles to new spectacles. A critical p-value of 0.05 was chosen to denote statistical significance for all analyses.

RESULTS

For 65 minutes watching 3D TV, the total score of asthenopia to 11 questions with HDCS and BVCSL was 21.89±11.28 and 9.51±12.28, respectively (Fig. 1). There was statistically significant reduction of asthenopia with BVCSL compared to HDCS ($p < 0.001$, paired t-test).

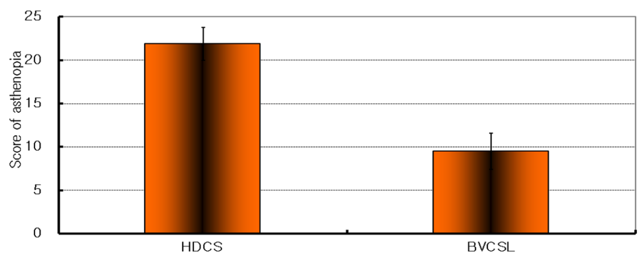

Fig. 1. Total score of asthenopia to 11 questions for 65 minutes watching 3D TV with HDCS and BVCSL. Error bars represent standard errors of mean (SEM).

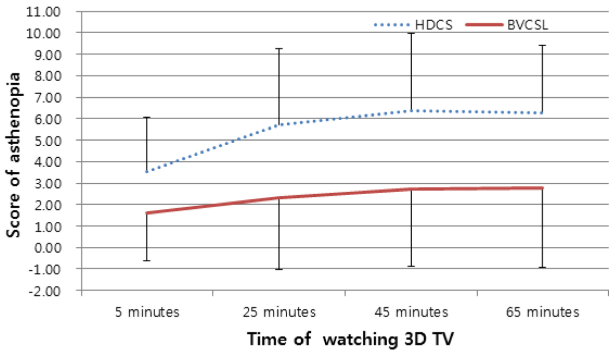

Fig. 2. Score of asthenopia to 11 questions for watching 3D TV with HDCS and BVCSL

The score of asthenopia in watching 3D TV with wearing HDCS was gradually and significantly increased from 3.54±2.55 at after 5 minutes to 6.26±3.15 at after 65 minutes (p<0.001, RM-ANOVA) (Fig. 2). The increasing of the asthenopia was statistically significant at 25, 45, and 65 minutes of watching 3D TV (all p<0.001, paired t-tests) compared to 5 minutes of watching 3D TV. The score of asthenopia in watching 3D TV with BVCSL was also gradually increased from 1.63±2.24 after 5 minutes to 2.80±3.74 after 65 minutes. However, there was no statistically significant change in the asthenopia over the 45 minutes of watching 3D TV with BVCSL (p=0.116, RM-ANOVA). And asthenopia in watching 3D TV with wearing BVCS was significantly lower than wearing HDCS at 5, 25, 45, and 65 minutes (all p<0.001, paired t-tests).

Table 1 presents the mean and standard deviations of the scores of asthenopia to 11 questions with wearing HDCS. The symptoms of eye straining, dry eye, sore eye, eye fatigue, and headache were significantly increased during watching 3D TV with HDCS for 65 minutes (all p<0.05, RM-ANOVAs). The increase of the symptoms in sore eye, eye fatigue, and headache was statistically significant (p<0.05,

Table 1. Scores of asthenopia to 11 questions with wearing HDCS and BVCSL

Symptoms	Glasses types	5 Minute	25 Minute	45 Minute	65 Minute	Total
Eye straining	HDCS	0.60±0.65	**0.97±0.95***	**1.11±0.93***	0.89±0.99	3.57±3.17
	BVCSL	0.51±0.70	**0.43±0.74**$^{+}$	**0.54±0.82**$^{+}$	**0.43±0.78**$^{+}$	**1.91±2.72**$^{+}$
Eye pain	HDCS	0.29±0.62	0.40±0.74	0.54±0.85	0.57±0.85	1.80±2.60
	BVCSL	0.14±0.36	0.17±0.45	**0.20±0.63**$^{+}$	**0.23±0.69**$^{+}$	**0.74±1.96**$^{+}$
Dry eye	HDCS	0.43±0.61	0.63±0.69	0.71±0.79	**0.86±0.88***	2.63±2.40
	BVCSL	**0.09±0.28**$^{+}$	**0.40±0.60***	**0.43±0.70***	**0.46±0.74***	**1.37±2.04**$^{+}$
Sore eye	HDCS	0.14±0.36	**0.43±0.70***	**0.60±0.74***	**0.60±0.77***	1.77±2.18
	BVCSL	0.14±0.36	0.23±0.43	**0.29±0.57**$^{+}$	0.40±0.69	1.06±1.51
Watery eye	HDCS	0.09±0.28	0.23±0.43	0.26±0.66	0.17±0.45	0.74±1.40
	BVCSL	0.06±0.24	0.11±0.32	0.09±0.28	0.09±0.28	**0.34±0.87**$^{+}$
Photophobia	HDCS	0.17±0.45	0.20±0.47	0.20±0.47	0.09±0.28	0.66±1.21
	BVCSL	0.03±0.17	**0.00±0.00**$^{+}$	0.03±0.17	0.03±0.17	**0.09±0.37**$^{+}$
Blur vision	HDCS	0.11±0.40	0.23±0.55	0.09±0.37	0.03±0.17	0.46±1.24
	BVCSL	0.00±0.00	**0.00±0.00**$^{+}$	0.00±0.00	0.03±0.17	0.03±0.17
Diplopia (Cross-talk)	HDCS	0.71±0.93	0.74±1.04	0.51±0.89	0.77±1.14	2.74±3.48
	BVCSL	**0.09±0.28**$^{+}$	**0.17±0.45**$^{+}$	**0.14±0.43**$^{+}$	**0.17±0.45**$^{+}$	**0.57±1.56**$^{+}$
Eye fatigue	HDCS	0.83±0.89	**1.26±0.85***	**1.57±0.85***	**1.51±0.85***	5.17±2.82
	BVCSL	**0.49±0.66**$^{+}$	**0.60±0.88**$^{+}$	**0.71±0.79**$^{+}$	**0.63±0.77**$^{+}$	**2.43±2.77**$^{+}$
Headache	HDCS	0.11±0.40	**0.40±0.74***	**0.57±0.78***	**0.63±0.88***	1.71±2.50
	BVCSL	0.09±0.28	0.20±0.53	**0.23±0.49**$^{+}$	**0.26±0.56**$^{+}$	0.77±1.59
Dizziness	HDCS	0.06±0.24	0.23±0.49	0.20±0.41	0.14±0.43	0.63±1.26
	BVCSL	0.00±0.00	**0.03±0.17**$^{+}$	0.09±0.28	0.09±0.28	**0.20±0.68**$^{+}$

The values represent the mean ± standard deviation.
Bold, significantly different; *, versus 5 minutes, p<0.05 by posthoc paired student t-test: +, HDCS versus BVCSL, by paired sample t-test

$p<0.01$, $p<0.05$, respectively, paired t-tests) by 25 minutes of watching 3D TV compared to 5 minutes of watching 3D TV. The increase of the symptom in eye straining was statistically significant at 25 and 45 minutes of watching 3D TV ($p\leq0.01$, $p<0.01$, respectively, paired t-tests) compared to 5 minutes of watching 3D TV. The symptom of eye dry eye was statistically significant only at 65 minutes of watching 3D TV ($p<0.05$, paired t-test) compared to 5 minutes of watching 3D TV. However, there were no changes of the symptoms in eye pain, watery eye, photophobia, blur vision, diplopia, and dizziness during watching 3D TV for 65 minutes (all $p\geq0.089$, RM-ANOVAs).

The symptom of dry eye was significantly increased during watching 3D TV with wearing BVCSL ($p=0.001$, RM-ANOVA) for 65 minutes. The symptom of dry eye was significantly increased ($p\leq0.019$, paired t-tests) by 25 minutes of watching 3D TV compared to 5 minutes of watching 3D TV. However, there were no changes in the symptoms of eye straining, eye pain, sore eye, watery eye, photophobia, blur vision, diplopia, eye fatigue, headache, and dizziness during watching 3D TV for 65 minutes (all $p\geq0.119$, ANOVAs).

Diplopia, eye fatigue, eye straining and total symptoms with wearing BVCSL were significantly lower than with wearing HDCS at 5 minutes, 25 minutes, 45 minutes, 65 minutes (all $p\leq0.05$, paired t-tests). The symptom of dry eye was significantly reduced at 5 minutes, and total of watching 3D TV with BVCSL compared to HDCS (all $p\leq0.026$, paired t-tests). There were statistically significant reductions of photophobia and dizziness at 25 minutes, and

Table 2. Total scores of asthenopia of 5 groups with wearing HDCS and BVCSL

Symptoms	Glasses types	CP(n=5)	BIP(n=9)	VP(n=16)	BDYP(n=16)
Eye straining	HDCS	3.00±4.12	2.33±2.50	3.94±3.15	4.75±3.34
	BVCSL	2.40±3.78	2.22±3.53	2.38±2.96	**1.50±2.07**+
Eye pain	HDCS	1.60±4.12	0.78±1.64	2.81±3.23	2.50±3.35
	BVCSL	1.80±4.02	1.11±1.96	**0.69±1.58**+	**0.44±1.09**+
Dry eye	HDCS	3.20±2.77	3.44±2.96	1.94±2.21	2.25±2.21
	BVCSL	3.00±3.67	**1.44±1.74**+	1.13±1.63	**0.69±1.01**+
Sore eye	HDCS	1.80±3.03	1.56±1.59	2.25±2.46	1.50±2.00
	BVCSL	1.60±2.07	1.78±1.56	1.06±1.39	**0.63±1.41**+
Watery eye	HDCS	0.40±0.89	0.44±1.01	1.31±1.82	1.19±1.80
	BVCSL	0.00±0.00	0.22±0.44	0.50±0.97	**0.25±0.68**+
Photophobia	HDCS	0.24±0.45	0.44±0.88	0.88±1.41	0.81±1.38
	BVCSL	0.00±0.00	0.33±0.71	0.19±0.54	**0.00±0.00**+
Blur vision	HDCS	0.20±0.45	1.00±2.12	0.56±1.09	0.25±0.77
	BVCSL	0.20±0.45	0.00±0.00	0.00±0.00	0.00±0.00
Diplopia (Cross-talk)	HDCS	4.40±3.58	4.11±3.86	3.00±3.39	0.88±1.59
	BVCSL	2.00±3.08	**0.89±1.76**+	**0.31±1.01**+	**0.06±0.25**+
Eye fatigue	HDCS	4.40±2.61	4.67±2.96	5.31±3.16	6.13±2.96
	BVCSL	2.40±4.83	3.22±2.82	2.75±2.79	1.88±1.89
Headache	HDCS	1.80±1.79	0.78±1.56	2.31±3.30	2.31±2.91
	BVCSL	1.00±2.24	0.56±0.88	0.94±1.65	0.75±1.65
Dizziness	HDCS	1.40±1.95	1.00±1.73	0.75±1.39	0.25±0.58
	BVCSL	0.60±1.34	0.22±0.67	0.13±0.50	0.13±0.50

The values represent the mean ± standard deviation.
HDCS, habitual distance corrective spectacles; BVCSL, binocular vision corrective spectacles lenses; +, $p<0.05$ by paired sample t-test, HDCS versus BVCSL; CP, change correction power without prism; P, prism; n, number of subjects; BIP, base in prism; VP, vertical prism; BDYP, base down yoked prism

total of watching 3D TV with BVCSL compared to BVCSL (all $p<0.05$, paired t-tests). The reduction of headache was a statistically significant at 45 minutes, and 45 minutes of watching 3D TV with BVCSL compared to HDCS (all $p<0.05$, paired t-tests). There were statistically significant reductions of blur vision, sore eye, and watery eye at 25 minutes, 45 minutes and total of watching 3D TV with BVCSL compared to HDCS respectively ($p<0.05$, $p<0.05$, $p<0.05$, respectively, paired t-tests).

Table 2 presents the means of the total score of asthenopia of 4 groups to 11 questions with wearing HDCS and BVCSL. In CP group, all asthenopia was not significantly different between HDCS and BVCSL (all $p\geq0.05$, paired t-tests). However, dry eye and diplopia in the group of BIP were significantly lower for BVCSL than for HDCS ($p<0.05$, $p<0.05$, respectively, paired t-tests). In the group of VP eye pain, diplopia and eye fatigue were significantly reduced when wearing BVCSL than when wearing HDCS ($p<0.05$, $p<0.01$, $p<0.01$, respectively, paired t-tests). In the group of BDYP, eye straining, eye pain, dry eye, sore eye, watery eye, photophobia, diplopia, and eye fatigue were significantly reduced compared to HDCS (all $p < 0.05$, paired t-tests).

DISCUSSION

The eyes need to be pointed accurately to maintain stereopsis and singleness of vision. The eyes must also continuously convert or divert to make stereoscopic images, and accommodate to see clearly in 3D moving display. In the 3D viewing, exo- or eso- vergence can also be required more accurately than in real viewing to make stereoscopic images. Binocular dysfunctions, which the eyes cannot come together easily, can induce asthenopia not only in real 3D viewing[13,14] but also in 3D display viewing.[1] And elevation of gaze in 3D viewing may induce binocular disruption and strain. Correcting prisms and lenses used in this study may decrease the elevation of convergence or divergence and accommodation required in 3D viewing respectively. Mechanism to relation between convergence and accommodation in watching 3D TV differ from that in real viewing, and can increase more asthenopia than in real 3D viewing. Moreover, previous studies[4-7] have also reported that mismatching between accommodation and vergence in 3D viewing was main factor to induce 3D fatigue. People who have binocular dysfunctions may be more sensitive to sensory conflict, and mismatch between convergence and accommodation in watching 3D TV. This mismatching between convergence and accommodation occur by phoria and/or refractive error, and amount of the mismatching is depended on refractive error and/or phoria in not only 3D viewing but also real viewing. In real viewing, correction of phoria by prism or refractive error correction by lens can reduce asthenopia and visual fatigue. So, prism and lens correction used for this study may play a role to reduce visual fatigue in 3D viewing.

3D viewing images through 3D display images change real images to be smaller or larger. As convergence demand is increased to maintain fusion of right eye and left eye images, 3D image may appear to become smaller and move closer or toward the TV watcher. Controversially, as the divergence demand is increased to maintain fusion of two eyes images, 3D image may appear to become larger and move farther away or out. This change of image can alter the perceptual and vestibular demands of the physical stimuli, and their prismatic properties alter the vergence demand.[15] Simultaneously, input from eye movements is a likely cause of vestibular stimulation.[16] When seeing objects it also involve in two separate visual processing systems, focal process and ambient process.[17] The ambient visual process helps to work with sensory-motor information. 3D viewing by 3D display images may alter the ambient visual process. Vestibular stimulation and eye movement by changes of images without body moving, and ambient processing systems may cause dizzy, eye straining or other symptoms. Sensory conflict between the signals received by the three major spatial senses, which are the visual system, the vestibular system, and nonvestibular proprioception, can also lead to symptoms.[16,18]

This study also showed that dizzy, eye straining and other symptoms occurred with 3D viewing were reduced by correction glasses with prism and lens power. Specially, base-down yoked prism significantly reduced symptoms of eye straining, dryness, watery and diplopia. Rose and Torgerson[19] subscribed that yoked prisms can be a very effective tool in making changes in the oculomotor state, which thereby affects sensory function. Yoked prism re-adjusts the motor system, and sends information to the visual cortex. Kim *et al*.[20] studied reduce or decrease of dizzy using vertical yoked prism of glasses, reported that vertical base-down yoked prism reduced dizzy more than vertical base-up yoked prism. And they also reported that subjects who have esophoria at near felt less with vertical base-down yoked prism than with vertical base-up yoked prism. This study supported their results in 3D viewing condition as well.

And vertical prism also significantly reduced eye pain and diplopia. Diplopia called cross-talked may occur due to incomplete fusion of two eyes. Different images of two eyes in size, color, clearness or shape and disagreement between two eyes' visual lines at the object[21,22] increase possibility of incomplete fusion. Correction glasses used in this study increased clearness of two eyes using refractive error correction and agreement using horizontal or vertical prism. So correction of phoria/vergence-based binocular vision imbalance resulted in a significant reduction in diplopia and asthenopia both during and immediately following 65 minutes of 3D television viewing. An individual with binocular vision imbalance should be corrected/compensated with appropriate prisms prior to prolonged viewing of 3D television displays to reduce asthenopia/visual fatigue.

CONCLUSION

Asthenopia during 3D television viewing has a correlation with refractive error correction, binocular imbalance and vestibular condition. Correction of phoria/vergence-based binocular vision imbalance and yoked prism of base down direction can reduce asthenopia during 3D television viewing. An individual with binocular vision imbalance need corrected/compensated glasses with appropriate prisms prior to prolonged viewing of 3D television displays to reduce asthenopia/visual fatigue.

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양안시 교정안경의 3차원 텔레비전 시청 중 발생한 안정피로 감소

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투고일(2014년 08월 1일), 수정일(2014년 09월 2일), 게재확정일(2014년 9월 18일)

목적: 3D영상은 여러 분야에서 매우 유용하지만 일부 사람들에게 신체적인 불편함을 일으킨다. 본 연구는 신체적 불편함을 느끼는 사람에 있어서 그들의 상용안경을 착용했을 때와 양안시 교정안경을 착용을 때 안정피로의 타입과 정도를 평가하기 위함이다. **방법:** 성인 98명을 그들이 착용해 온 상용안경을 착용한 상태에서 3D 텔레비전(TV)을 65분간 시청한 후 안정피로가 가장 심하게 느끼는 35명(나이 32.2±4.4 yrs)을 대상으로 평가했다. 그런 다음 수평, 수직 또는 기저 하 방향의 동향프리즘을 부가한 양안시 교정안경을 착용하고 2.7 m 거리에서 65분간 3D TV를 시청하는 동안 안정피로의 정도를 수치로 재평가했다. 평가는 11가지 증상에 대해 4점 스케일(0=없음, 3=심함)로 하였다. 원거리 및 근거리 수평 사위는 하웰사위검사카드(Howell phoria card)로 측정하였으며 수직 사위는 마독스봉(Maddox rod)을 이용하였다. 3D TV 시청에 의해 발생되는 증상을 상용안경을 착용했을 때와 양안시 교정안경을 착용했을 때를 비교하였다. **결과:** 양안시 교정 안경을 착용한 상태에서 3D TV를 시청할 때 시청 5, 25, 45, 65분에서 상용안경을 착용하고 시청할 때 보다 안정피로가 유의수준에서 낮았다(all $p<0.001$, paired t-tests). 굴절이상도만 필요로 하는 그룹에서는 상용안경 착용과 양안시 교정안경을 착용하고 시청 할 때는 모든 안정피로에서 유의 수준에서 차이가 없었다. 그러나 양안시 이상의 프리즘 교정 그룹에서 안정피로는 양안교정 안경 착용이 상용안경 착용 때 보다 유의 수준에서 낮았다(all $p<0.05$). **결론:** 사위/이향 안구 운동을 기초로 한 양안시 이상의 안경교정은 3D 시청 중에 안정피로를 낮출 수 있다. 양안시 이상을 가진 사람은 안정피로를 줄이기 위해 3D TV를 오래 보기 전에 적절한 프리즘이 필요하다.

주제어: 3D 텔레비전, 안정피로, 양안시 이상, 사위