· Original article ·

Effects of persistent viewing of 3D TV on human visual function

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持续观看 3D 电视对视功能的影响

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摘要

目的:研究持续观看 3D 电视对视功能的影响,以及探索不同视功能参数之间的关系。

方法:本研究录入 19 位受试者,每位受试者观看 90 分钟的 2D 电视或 90 分钟的 3D 电视,两部电视观看间隔时间为一周,顺序随机。每次观看电视前及观看后 15min 内都做相关视功能检查,检查包括以下四种视功能参数:调节功能(调节反应、调节微波动、调节灵敏度、正相对调节、负相对调节、AC/A),融像性聚散功能(远距负融像性聚散功能、远距正融像性聚散功能、近距负融像性聚散功能、近距正融像性聚散功能),隐斜量(远距隐斜量、近距隐斜量),立体视。

结果:无论是与观看前的基础值比较,还是与观看 2D 电视后的数据比较,观看 3D 电视后近距离调节反应增加,汇聚减少,远距隐斜量向外隐斜改变($P<0.05$)。

结论:持续观看 3D 电视会对人们的视功能有一定影响,主要是打破了调节和聚散系统的平衡。厂家和公众应该引起重视,将调节功能、融像性聚散功能、隐斜量等参数作为评估 3D 电视安全性的指标。

关键词:3D 电视;视功能;调节;融像性聚散;隐斜量;立体视

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Abstract

• AIM: To comprehensively identify the effects of persistent viewing of 3D TV on visual function and find out the relationship between different visual functional parameters.

• METHODS: The following four visual functional parameters: accommodation (accommodative response; accommodative microfluctuation; accommodative facility; PRA, positive relative accommodation; NRA, negative relative accommodation; gradient AC/A, the gradient accommodative convergence to accommodation ratio), vergence (DBI, distance base-in; DBO, distance base-out; NBI, near base-in; NBO, near base-out), phoria (distance and near lateral phoria), and stereopsis were measured for nineteen health participants before and after viewed 2D TV for 90min and 3D TV for 90min.

• RESULTS: Both compared with the baseline data and the data after 2D viewing, increased near accommodative responses, decreased convergence, changed phoria (more exophoric) at distance were detected after 3D TV viewing (all $P<0.05$).

• CONCLUSION: Prolonged viewing of 3D TV will influence human visual function, especially the disruption of the natural relationship between binocular convergence and accommodation induced by conflicting stimulus. Manufacturers and the public should consider the parameters of accommodation, vergence, and phoria as main indicators for detecting the safety of 3D TV.

• KEYWORDS: 3D TV; visual function; accommodation; vergence; phoria; stereopsis

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INTRODUCTION

Stereoscopic 3-dimensional (3D) display technology (such as cinema, television, gaming, and mobile devices) is becoming very popular, and as a result, the public's concerns about the adverse effects of this technology on visual function and health have increased. Previous studies have indicated that viewing 3D displays could lead to visual dysfunction and fatigue syndrome, such as blurred vision, eyestrain, and drowsiness[1-7]. There are several possible

Table 1 Participant demographics and baseline measurements of visual function $\bar{x}\pm s$

No.	Gender	Age (a)	Phoria at near (Δ)	Phoria at distance (Δ)	Refraction (SE, D)	Stereopsis (arcsec)
11	F	24.27±1.56	−1.00±6.52	0.32±2.58	−1.50±1.09	39.55±16.80
8	M	23.25±1.49	−2.94±3.09	−1.44±1.92	−1.49±1.04	41.25±15.53

n=19. SE: Spherical equivalent; D: Diopters.

causes for the visual dysfunction. Based on published studies, the major cause is the disruption of the natural relationship between binocular convergence and accommodation[8-11].

Several studies have compared the visual functional parameters before and after viewing 3D displays, and reported that a loss of balance between the accommodative and convergence systems can be detected after viewing 3D displays. There were also a few studies evaluating the visual function while viewing 3D displays. For instance, Torii *et al*[12] dynamically evaluated the accommodative responses and convergence of subjects when they were viewing 3D images. Based on these studies, there could be a disruption of the natural relationship between binocular convergence and accommodation induced by 3D displays viewing. Interestingly, in a study of Trotter *et al*[13], they found the visual responsiveness of neuron to the presentation of random dots stereogram was affected by the viewing distance, and they attributed this effect to extraretinal factors, such as accommodation or vengence. Furthermore, phoria closely associates with accommodation and vergence[14-16].

Due to the disruption of the natural relationship between convergence and accommodation, and the consequential effects on stereopsis and phoria, it's interesting and important to study how prolonged viewing of 3D TV affect those functions, and explore the relationship among them. However, we are not aware of any published data systematically evaluating the effects of 3D TV viewing on these visual functional parameters simultaneously.

In this study, we objectively and comprehensively investigated the effects on visual functional parameters (accommodation, vergence, phoria, and stereopsis) of prolonged viewing of shutter-type 3D TV, which has the major share of the 3D TV market and one of the most popular 3D displays in our daily life.

SUBJECTS AND METHODS

Subjects Nineteen healthy adults, including 8 males and 11 females with an average age of 23.84±1.57y (range, 21 to 26), were recruited into the study. Table 1 shows the participant demographics. All participants had an anisometropia ≤1.00 D, monocular best-corrected visual acuity ≥20/20, and TNO stereoacuity ≤60 arcsec. None of the participants had abnormalities of eye position or movement, or other organic ocular diseases.

Laboratory Environment and Experimental Equipment To simulate the cinema-viewing environment, the participants watched 3D TV and 2D TV in a dark environment without fluorescent lighting. The shutter 3D TV UA46D6000SJ (Samsung, Korea) was utilized as a display for both 3D and 2D versions in the study, with the following parameters: 46-inch screen, light-emitting diode (LED) backlight lamp, 1920 x 1080 display resolution, 200 Hz image refresh frequency (100 Hz per eye), and a 3D HyperReal engine with a backlight of 20 lumens, contrast of 100, brightness of 100 lumens, definition of 59, chroma of 50, and hue of red 50/ green 50.

The participants' accommodative responses and microfluctuations were measured with a WAM-5500 auto refractometer (Grand Seiko, Japan). Phoria at distances of 6 m and 40 cm were measured using von Graefe method. The gradient accommodative convergence to accommodation (AC/A) ratio was assessed using the gradient method described by von Noorden and Campos[17]. Stereopsis was tested by using a TNO random dot stereogram at a distance of 40 cm; the accommodative facility was examined by using a ±2.0 D flipper at a distance of 40 cm; and PRA, NRA, fusional vergence (break) were all measured behind a Topcon IS-600 phoropter (Topcon Medical Systems, Inc., Japan).

Target During Binocular Visual Measurement The distance sighting target that was used to measure a participant's accommodative response and microfluctuations was the standard logarithmic visual acuity chart with an "E" shaped target at a distance of 6 m (corresponding to a visual acuity of 20/400). The near sighting target was adopted from rapid serial visual presentation (RSVP) software[18-20], and the targets, which were individual Chinese characters of 12-point font size from a novel, were presented sequentially. The RSVP targets were presented on a 14-inch LCD screen at a presentation speed of 300 words per minute. The accommodative response of the right eye during a 3-minute period was measured 3 times each at a distance of 6 m (the accommodative stimulus was regarded as 0 D), 40 cm (the accommodative stimulus was regarded as 2.5 D), and 25 cm (the accommodative stimulus was regarded as 4 D). To avoid any possibility of interference due to alterations in the brightness of the environment, the screens of the equipment being used to measure visual function were the only lit or reflective objects in the laboratory.

Experimental Approach Each participant had eye examination one week prior to watching any displays. The eye examination included an inquiry of the participant's ocular and medical histories, slit lamp examination of the anterior and posterior segments, and the following four aspects of visual function: accommodation (accommodative response; accommodative microfluctuations; accommodative facility; PRA, positive relative accommodation; NRA, negative relative accommodation; gradient AC/A, the gradient accommodative convergence to accommodation ratio), vergence (DBI, distance base-in; DBO, distance base-out; NBI, near base-in; NBO, near base-out), phoria (distance and near lateral phoria), and stereopsis. Results of all examinations above were regarded as the baseline data.

On the testing day, the participants watched a 90min 3D TV at a suggested distance of 2.5 m. While viewing 3D TV, the

Table 2 Changes of parameters after watching 3D and 2D TV, and the relationship between them $\bar{x}\pm s$

Parameter	Pre	After 3D	After 2D
Response			
6 m	0.408±0.328	0.377±0.318	0.440±0.347
40 cm	1.681±0.256	1.730±0.281	1.620±0.232
25 cm	2.522±0.328	2.636±0.331^{zw}	2.456±0.316
Microfluctuations			
6 m	0.191±0.093	0.200±0.098	0.235±0.053
40 cm	0.189±0.094	0.183±0.055	0.224±0.067
25 cm	0.145±0.053	0.193±0.062^{z}	0.217±0.061^{z}
Acc f (C/min)	18.394±3.430	18.289±4.470	19.210±4.697
AC/A (Δ/D)	3.947±2.172	3.790±1.465	3.105±2.125
PRA (D)	-2.486±0.847	-3.039±1.211^{zw}	-4.026±1.823^{z}
NRA (D)	2.302±0.543	2.289±0.501	2.460±0.487
Vergence			
DBI (Δ)	11.684±3.092	11.894±3.089	10.947±2.697
NBI (Δ)	23.333±5.259	23.800±5.212	25.266±3.555^{z}
DBO (Δ)	20.052±7.912	18.842±8.057	17.894±8.082
NBO (Δ)	29.210±4.802	24.921±9.866^{z}	24.105±8.627^{z}
Phoria			
Distance (Δ)	-0.421±2.433	-1.684±2.206^{zw}	0.026±2.163
Near (Δ)	-1.815±5.315	-2.736±4.120	-1.710±6.133
Stereopsis (arcsec)	40.263±15.853	33.156±15.475	38.684±15.261

D: Accommodation. The data shown are the mean ± standard deviation. $n = 19$. Abbreviations: Acc f, Accommodative facility; AC/A, the ratio of the gradient of accommodative convergence to accommodation; PRA, Positive relative accommodation; NRA, Negative relative accommodation; DBI, distance base-in; DBO, distance base-out; NBI, near base-in; NBO, near base-out. $^{z}P < 0.05$ while compared the parameters after watching 3D TV or 2D TV with the baseline data. $^{w}P < 0.05$ while compared parameters after watching 3D TV with parameters after watching 2D TV.

participants wore shutter-type stereo glasses. The measurements, consisting of the items described above, were performed within 15min after the participants finished the 3D TV viewing. One week later, the participants watched 2D TV for 90min under the same condition. The same measurements described above were performed after the participants finished the 2D TV viewing.

Statistical Analysis SPSS 19.0 software was utilized for the statistical analyses of this study. Paired sample t-test was used to compare the measurements of visual function before and after the participants viewed 3D or 2D TV. The repeated measures ANOVA was used to compare the measurements of visual function after the participants viewed 3D and 2D TV. $P < 0.05$ was considered statistically significant.

RESULTS

Changes of Parameters after Watching 3D TV and Changes of Parameters after Watching 2D TV Table 2 summarizes the changes of visual function after watching 3D TV and changes of visual function after watching 2D TV. The near and distant accommodative responses of all participants had the tendency to increase and significant increase of accommodative response at 25 cm ($P<0.05$) was found after viewing 3D TV ($P<0.05$), which were not found after they viewed 2D TV. The accommodative microfluctuations increased significantly at the distance of 25 cm both after they viewed 3D TV and 2D TV ($P<0.05$). The PRA increased significantly both after watching 3D TV and 2D TV (both $P<0.05$). The NBO decreased and NBI increased significantly after watching 2D TV (both $P<0.05$), however only NBO decreased significantly after watching 3D TV ($P<0.05$). Significant change of phoria (more exophoric) at distance were observed after they viewed 3D TV ($P<0.05$), which was not found after they viewed 2D TV. No other visual functional parameters demonstrated significant difference after viewing 3D TV or 2D TV.

Comparison of Parameters after Watching 3D TV and 2D TV Table 2 also shows comparison of visual functional parameters after watching 3D and 2D TV. After the participants viewed 3D TV, we detected an increased accommodative response at 25 cm, increased PRA, changed phoria (more exophoric) at distance (all $P<0.05$) as compared with 2D TV.

DISCUSSION

Viewing stereoscopic images that are presented on a flat surface is different from viewing that in the real world. While viewing an object in the real world, a person uses convergence to bring the two eyes into correct position and use accommodation to bring that object's retina image into focus. There is no convergence-accommodation conflict. In 3D TV, the images on screen are in focus and the distance from the screen to the eye is fixed. Therefore, the demand of accommodation is fixed. However, various amount of disparities are introduced between the images to demand the convergence to be located geometrically in front of, or behind, the screen. Therefore, the demands for accommodation and for convergence do not match, inducing a convergence - accommodation conflict[9-11]. Based on published studies, the mechanisms of visual dysfunction caused by viewing 3D video have been summarized as two major causes. The first one was visual disturbance due to the mismatch between accommodation and convergence. The second one was the large disparity between binocular parallax, an overload on visual information fusion[12]. All of these disturbances would ultimately have an adverse effect on visual health and result in the disability of accommodation and fusional vergence, or visual fatigue[1-3].

Accommodation Parameters In this study, we objectively and comprehensively described the alterations of accommodation after the participants viewed 3D TV by measuring accommodative response and microfluctuation both at distance and at near. Our findings demonstrated that the participants' near accommodative responses increased after they viewed 3D TV as compared with 2D TV. This result matched previous studies well. For instance, Torii *et al*[12] measured the dynamic accommodative and convergent responses of the participants after they viewed 3D TV and determined that 4 out of 7 exhibited a transient over - accommodative response. In a study by Fujikado[21], participants who had viewed 3D video experienced transient low - diopter myopia (0.2 D) due to excessive accommodation. This study did not report significant alterations in participants' microfluctuations; however, a single sighting target was used, and the duration of measurement, which was obtained by using spectrum analysis, was short. Therefore, the precision and accuracy might not have been sufficient. In the current study, first of all, to simulate reading activity in natural conditions and accurately reflect real - time dynamic responses, all measurements of visual function were obtained with an infrared automatic optometry instrument and RSVP software[22]. Secondly, we also determined that participants' microfluctuations (the viability of the accommodative response) increased in response to an accommodative stimulus of 4 D (25 cm) both after they viewed 3D TV and 2D TV. The increased accommodative response and increased microfluctuation may occur if there is a convergence - accommodation conflict as we mentioned before. This conflict will increase accommodation and the burden on the accommodative system and result in incomplete relaxation of the visual system for a short time after viewing 3D TV[12].

Vergence Parameters In our study, we evaluated two factors of vergence. The convergence amplitudes were evaluated by measuring DBO and NBO, and the divergence amplitudes were evaluated by measuring DBI and NBI. The results indicated that the ability of participants to perform positive fusional vergence at the distance of 40 cm decreased significantly both after they viewed 3D TV and 2D TV, though no significant differences between them. Previous studies suggested that the changed reliance or fusional vergence could result in muscle and neural adaptation fatigue and lead to a series of visual symptoms[23-26]. In addition, Wee *et al*[27] determined that viewing 3D movies with polarized glasses for 30min increased accommodative responses and increased near point of convergence (decreased ability of convergence). The results matched our study well.

Phoria Parameters In our study, we evaluated the phoria both at near and distance. We found that the phoria both at near and distance that was experienced by participants have the trend to be exophoria after watching 3D TV as compared with 2D TV. Similarly, Karpicka and Howarth[28] determined that the phoria was more exophoric after playing a computer game in 3D condition as compared with 2D condition. The changed phoria (more exophoric) might be related to the participants' reduced convergence ability. The decreased positive fusional vergence could also produce various symptoms of visual fatigue such as blurred vision, convergence fatigue, headache, swollen eyes, and head pain[5-7].

Based on previous studies, it would be logical to indicate that the decreased convergence and changed phoria (more exophoric) after 3D TV viewing may due to the adaptation of the vergence and accommodative controllers[28-29]. According to a study of Eadie *et al*[30], the AC/A and CA/C decreased after viewing the stereoscopic virtual reality stimulus for 60 min. The results demonstrated that the stereoscopic stimulus can initiate changes in the crosslink interaction between vergence and accommodation by altering the AC/A and CA/C ratios, which supported the idea that vergence accommodation and accommodative vergence are capable of adaptation while viewing stereoscopic stimulus. In our study, although it was not significant, the AC/A ratio had the tendency to decrease as compared with the baseline date after viewing 3D TV (3.790 ± 1.465 Δ/D *vs.* 3.947 ± 2.172 Δ/D).

Although decreased convergence was found both after 3D TV viewing and 2D TV viewing, changed phoria (more exophoric) was only found after 3D TV viewing. The results indicated that adaptation might occur both in 3D TV viewing and 2D TV viewing, but adaptation in 3D TV viewing might be stronger than that in 2D TV viewing. While viewing the 3D TV, because of the conflicting stimulus which was different with the stimulus in 2D TV, the natural relationship between binocular convergence and accommodation was disrupted in order to perceive a single clear image, inducing more adaptation. As reported by Emoto *et al*[24], the decreased fusional amplitude after viewing of stereoscopic images recovered to pre - viewing levels after taking a 10min relaxation. Therefore, we assumed that the interaction between accommodation and vergence could recover after taking a 10min relaxation.

Stereopsis Parameters Stereopsis is the highest form of binocular visual processing, in which relative depth information is extracted from two slightly different retinal images. Based on the study of Trotter *et al*[13], the visual responsiveness of neuron to the presentation of random dots stereogram might be affected by accommodation or vergence. Although we detected changed accommodation and vergence parameters after 3D TV viewing in this study, stereopsis was not significantly changed after 3D TV viewing both at distance and near. We attribute this difference to the following factors. First, the subjects in study of Trotter *et al*[13] were behaving monkeys, which were different with the human being we tested in this study. Second, the measurement conducted in the study of Trotter *et al*[13] was the objective responsiveness of neuron in cortical area V1 to the presentation of random dots stereogram, while the method of measurement conducted in our study was the subjective response to the TNO random dots stereogram.

In this study, we compared the data after watching 3D and 2D TV with single baseline data that were measured one week before watching any displays. We thought the baseline data reflected the usual ophthalmological status. There may be concern that separately measuring pre-data in day of watching 3D TV and 2D TV is better for comparative analysis. However, Wee *et al*[27] thought this method may develop confounding effects because predate of 3D day could differ from those of 2D day.

Our study has limitations. Although the majority of users of 3D display are children and adolescents, the participants of the current study were all healthy adults. Given that the visual system of children and adolescents is immature, viewing 3D TV for prolonged periods may affect visual function more easily and play a more important role in the occurrence and progression of myopia. Therefore, research that involves children and adolescents is necessary. In addition, the focus of the current study was the short-term influence of prolonged viewing of 3D TV on visual function, future studies should investigate the long-term effects.

In summary, in this study, we objectively and comprehensively investigated the effects on visual function of prolonged viewing 3D TV. It is fairly certain that prolonged viewing of 3D TV will influence human visual function, especially the disruption of the natural relationship between binocular convergence and accommodation induced by conflicting stimulus. And the the machnism of visual disfunction after viewing 3D TV may be contributed to the adaptation of accommodation and vergence controllers while viewing 3D TV. These results show that viewers who used to viewing 3D TV should therefore familiarize themselves with the disadvantages of the 3D TV in order to avoid visual dysfunction. In addition, we strongly believe that visual functional parameters such as accommodation, vergence, and phoria can be regarded as metrics for evaluating the effects of viewing 3D TV on visual function.

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