Visual fatigue caused by viewing stereoscopic motion images: Background, theories, and observations

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Available online 1 October 2007

Abstract

The background, theories, and observations on visual stress possibly caused by viewing stereoscopic motion images are reviewed. Visual fatigue caused by stereoscopic images is a safety issue. Fatigue is possible caused by the discrepancy between accommodative and convergence stimuli that are included in the image. Studies on accommodation and convergence are surveyed and an explanation regarding the characteristics of these functions is offered. Studies in the literature on changes in oculomotor function after viewing stereoscopic images, including changes in pupillary responses, are discussed. Evaluation of visual fatigue, particularly in relation to different methods of viewing stereoscopic displays is described.

Keywords: Stereoscopic image; Visual stress; Visual fatigue; Accommodation; Convergence

1. Introduction

Visual fatigue is a wide range of visual symptoms, including tiredness, headaches, and soreness of the eyes [1]. Visual fatigue can be caused by demands on early visual functions such as focusing and converging the eyes on a near object and may also involve central cortical structures, for example, those involved in viewing a wide-field, high-contrast, geometric pattern [2]. Most visual tasks in everyday life can contribute in some way to visual fatigue, especially when the eyes are used for long periods. Visual fatigue may occur for example when doing fine work, when reading poorly printed texts and low-quality computer images, when reading in inadequate or intense lighting, and when exposed to flickering lights or to geometric patterns, as well as when a person has uncorrected ametropia. Visual fatigue can also arise when people are viewing stereoscopic motion images. Stereoscopic images used for entertainment must be particularly free of visual fatigue because they are not essential for our lives.

Visual fatigue as a topic of study came to the fore after the 1970s with the introduction of visual display units (VDUs) in the office environment [3]. As a result, international and domestic organizations such as ISO (International Organization for Standardizing) published recommendations for working environments using VDU, in order to reduce fatigue symptoms [4]. In spite of these measures, many people suffer from visual fatigue even today, although it is often said that the number of people reporting visual fatigue in the office environment has decreased since the recommendations were implemented.

Visual fatigue or asthenopia is sometimes referred to as eyestrain. Generally “strain” indicates the elastic distortion caused by “stress”. If the stress is too high, or if the stress continues for a long time, irreversible changes may result. A number of studies on myopia [5–7] has suggested that similar to mental strain, eyestrain is also a warning of possible irreversible health damage.

Symptoms of visual fatigue generally include eyestrain, dried mucus or tears around the eyelids, feeling of pressure in the eyes, ache around the eyes, discomfort when the eyes
are open, hot eyes, difficulty in focusing or blurred vision, stiff shoulders, and headaches [1]. Very little is known about the mechanisms of fatigue, this is partly attributed to the fact that fatigue, and its symptoms are generally assessed subjectively. Although many studies have attempted to measure human stress/strain objectively as described below. Among the known studies on visual fatigue, Wilkins has published a book on visual stress [2]. He has proposed that when a person looks at a specific pattern (such as fine stripes), a part of the brain is strongly stimulated, resulting in migraine and/or fatigue. Wilkins has suggested that people who easily develop migraine also tend to be affected by eyestrain.

In this review, firstly, differences between natural depth perception and depth perception in stereoscopic images are described. Then, types of visual stress resulting from different instruments used for viewing stereoscopic images are identified. After that, methods of evaluating visual fatigue and binocular rivalry are discussed. Next, accommodation and convergence functions and their discrepancies are reviewed. Finally, the literature on changes in oculomotor balance and pupillary responses caused by viewing images are discussed.

2. Depth perception and the stereoscopic image

Depth perception uses several cues that can be categorized into the psychological and physiological realms. Psychological cues include perspective, overlap, air perspective, shadow, apparent size, texture, etc., and physiological cues which have been suggested include, binocular parallax, motion parallax, accommodation, and convergence. Binocular parallax refers to difference in image between the two eyes caused by their different location, and binocular disparity refers to retinal image difference between the left and right eyes when convergence is achieved to a specific distance.Physiologically, binocular disparity gives a sense of depth (stereopsis).

Although various developments are underway to realize true three-dimensional images, an inexpensive system capable of this task has yet to be developed. To date, it has only been easily possible to realize true stereoscopic images. The problem is that whereas binocular disparity can be easily changed, the screen position or image position produced in the air by an optical systems cannot be changed easily, resulting in different demands on accommodation and convergence. This discrepancy between accommodation and convergence demand may be highly stressful for the visual system.

3. Instruments for viewing stereoscopic image

A stereoscopic image is produced by presenting one image to the left eye, and another to the right eye. The presentation of these two images may be realized by several methods [8]. In addition to the possibility of stereoscopic images causing fatigue, it is also possible that characteris-
suppression of torsional eye movement to head roll motion is small compared to the horizontal and vertical movements [15]. Thus, images on HMDs are complex and unnatural, and as a result, cause modifications of the vestibular system. The long-term effects of VOR suppression on health are yet unknown. It is however known that image sickness is more easily induced when using HMDs in comparison to conventional displays, possible because of the characteristics of HMDs discussed above [15].

Stereoscopic viewers such as were common in Victorian times with combined two-lens systems without a rigid frame are frequently used for viewing static stereoscopic pictures. Lenses focus the image at infinity producing a zero accommodative stimulus. Images are separated by about 6 cm. The stimulus for convergence for non-disparity portion such as frames of the picture is infinity if the inter-pupillary distance (IPD) of the viewing people is equal to the separation distance. Thus both accommodative and convergence stimuli coincide at infinity. Simplified paper mounted lenses are also available. With these, axes of the two eye lenses cannot be kept at the desirable alignment, and therefore, differences in binocular images discussed above take place easily.

The actual setting up of stereoscopic imaging systems, such as the appropriate shift of the binocular images on the screen, is a controversial issue. Here, systems using two projectors are assumed. If this shift was zero, convergence and accommodation demands have no discrepancy at the screen distance. However, for making objects at infinity, images of the objects should be separated on the screen about 60 mm (IPD) irrespective of the distance between screen and viewers (Fig. 2a). Projected size of the image and shift of the two images are difficult to control since they depend on the screen size, projection distance and projection lens (Fig. 2b). This system cannot avoid divergent alignment of both eyes at a point further than infinity when images are projected larger than expected. To avoid divergent alignment, there is an easy alternative method that frames of the two images are separated at IPD on the screen. Any objects taken by a pair of cameras with parallel axes will shift inward from the frame position on the screen, and have no divergent alignment (Fig. 2c).

4. Evaluation of visual fatigue

It is important to evaluate visual fatigue and sickness caused by viewing images using subjective methods. The simulator sickness questionnaire (SSQ) developed by Kennedy et al. [16] is a well known and a well established useful measurement tool for evaluating motion sickness caused by motion images. Kuze and Ukai [17] used a newly developed questionnaire to subjectively assess symptoms caused by viewing various types of motion images. The questionnaire included items on visual fatigue and sickness evenly, and the two factors were clearly distinguished. This was applied to four types of moving images; playing a TV game using a HMD/TV, viewing images with and without stabilization of camera shake, viewing a movie with and without colour-break-up and viewing either a stereoscopic movie (anaglyph method) or a two-dimensional movie. Factor analysis revealed five factors: (1) eye strain, (2) general discomfort, (3) nausea, (4) focusing difficulty, and (5) headache, which were effective for classifying motion images. Results indicated that stereoscopic movies caused severe visual fatigue compared to other media.

One of the symptoms of visual fatigue is focusing difficulty and accommodative functions have been identified as a valuable index of fatigue. For example, seven methods of measuring visual fatigue caused by VDU work, accommodation, visual acuity, pupil diameter, critical fusion frequency (CFF), eye movement velocity, subjective rating of visual fatigue, and task performance, were compared [18]. In the study, however, subjective rating was not parallel to the other methods consistently. Further, accommodative functions depend on age and accommodative responses are too small in presbyopic people to detect abnormality, even though visual fatigue is a common symptom in the early stage of presbyopia (40s).

Pupillary responses reflect the balance of autonomic nervous activity. Moreover, they are also related to the accommodative function, and therefore, as described below in Section 7, many investigators consider that the role of the pupil in near reflex should be investigated.

It is known that certain proteins in the saliva increase with mental and/or physical stress. Chromogranin A...
(CgA) is one such protein that respond only to mental stress and therefore could be used as a marker for fatigue [19]. It has been used for example, to evaluate visual fatigue before and after presenting a visual load using images with and without colour break-up by using one chip DLP projectors [20].

5. Accommodation and convergence discrepancy

This section focuses on the issue of the type of accommodative and convergence responses that would be evoked with an unnatural combination of stimuli such as those found in stereoscopic images. Discrepancy between accommodative and vergence stimuli is common in stereoscopic images, because accommodation should respond to the screen/image position but disparity of the two images for both eyes, vergence stimulus, varies time-to-time. Usually, accommodation and convergence responses are closely related. However, they can also differ depending on the stimuli. If the discrepancy is small, the two functions respond correctly, i.e., differently. It is often said that, this is unnatural, results in visual stress and causes visual fatigue.

A brief review on the characteristics of accommodation and vergence is presented in this section. It will also set the stage for Section 6, in which changes in oculomotor balance after viewing stereoscopic images are discussed.

Accommodation has limits for both near and distant viewing. Displacement of the far point of accommodation from infinity is known as ametropia. Near point of accommodation changes because of age and the resulting subjective feeling of inconvenience experienced in daily life is known as presbyopia. When no accommodative stimulus is available, such as in darkness or in an empty field, accommodation stays in the intermediate position between the far and the near points. This is known as tonic accommodation. Tonic accommodation is affected by visual fatigue [6,21,22]. Visual targets further or closer than tonic accommodative point cannot evoke precise accommodation with errors being biased toward the tonic position. Such errors are known as accommodative lead or lag (see Fig. 3). After accommodating to a different position from the tonic accommodative position, tonic position shifts from the initial position. This is known as the adaptation of accommodation [23,24].

Similarly, convergence has a limit known as the fusional limit that usually has a wider range than the accommodation range, especially in the aged. This is because the convergence function does not decrease with age, as is the case with the accommodative function. The inaccuracy of convergence, known as fixation disparity [25], is similar to the accommodative lag or lead. It is small and changes with distance in a complex manner, with large inter-individual...
variation. Vergence state under the no stimulus condition is known as phoria, and changes in phoria after fixation at a certain distance is known as phoria adaptation, vergence adaptation, or prism adaptation [26,27]. Accommodation and convergence range is sometimes lowered in VDU workers [28].

An accommodative response to a stimulus in the absence of a stimulus for convergence, e.g., when one eye is occluded, can elicit convergence responses, known as accommodative convergence as shown in Fig. 4. Ratio of accommodative convergence to the unit accommodation (AC/A ratio) shows the power of accommodative convergence. Convergence accommodation and ratio of convergence accommodation to the unit convergence (CA/C ratio) can also be similarly defined as shown in Fig. 5. Pinholes in front of both eyes enable this. Pinholes placed near the lens generally void the effect of focusing and feedback control loop of accommodation is opened. However, pinholes should move as eyes move. No-transparent contact lenses with pinholes enable this, but measurement of accommodation is difficult through the pinholes. Alternately, difference of Gaussian (DoG) patterns as shown in Fig. 5 can be used [29]. These patterns look extremely blurred, and accommodative effort is useless even if the viewer wishes to see clearly. AC/A and CA/C ratios are changed by the adaptation of accommodation and vergence [30,31].

Several studies [32,33] have recorded accommodation and convergence responses when viewing stereoscopic images. Fig. 6 shows the recordings of accommodative and convergence responses to the step changes in depth in a stereoscopic display (parallax barrier method) taken by Ukai and Kato [33]. Unstable accommodative and convergence responses suggest difficulty in fusing binocular images under the conflicted accommodative and convergence demand.
Quantitative analysis of accommodative responses is not easy because it has an inherent inaccuracy due to accommodative lag and lead. The relationship between spatial frequency components of visual targets and accommodation responses has been extensively investigated (e.g., [34,35]). If the pupil is small, depth-of-focus increases and the accommodation error is permitted [36]. Okada et al. [37] measured accommodative responses when viewing stereoscopic displays. They hypothesized that these responses were the equilibrium point between convergence-driven accommodation that pulls accommodation toward a position closer to the viewer, and defocus-driven accommodation that pushes it to stay at the screen position. In order to support their hypothesis, the demand of defocus-driven accommodation was reduced by blurring, i.e., by reducing the higher spatial frequency components of the visual target. The remaining low spatial frequency components were less affected by defocus, and therefore, inaccurate accommodation was permitted. Fig. 7a shows accommodative responses that clearly varied with target blur when viewing stereoscopic images. These results are schematically redrawn in Fig. 7b.

Torii et al. [38] have also measured accommodative and convergence responses to the step changes in stereoscopic depth similar to Ukai and Kato [33], one of their subjects had accommodative and convergence oscillation with difficulty to fuse when the target had a higher spatial components, however, this oscillation diminished when the target was spatial low-pass filtered.

Quality of images on the display is continuously improving and this is enhancing many aspects of image reality, which is a desirable development. However, according to Okada et al. [37] and Torii et al. [38] as discussed above, improvement of image quality, when stereoscopic system is derived, increases the discrepancy of accommodation and convergence and may cause increased visual fatigue. Recently, a viewing system that can change the apparent screen distance for accommodative stimuli [39] have been designed to reduce the discrepancy between accommodation and convergence. As image quality improves, it is expected that these systems will become increasingly necessary.

Under natural conditions, accommodation and convergence are strongly affected by the proximity of objects. However, proximity of objects cannot be easily controlled in the laboratory while many attempts have been carried out [40,41]. Similarly, safety issues related to stereoscopic images are discussed in this article but the contents of the images, such as stories which can give prediction of distance change, relation between objects where attention of the viewer is given and background, and static and dynamic screen plays which emphasize the depth perception, are hardly dealt with at present. Readers who are interested in this topic are referred to the study by Yano et al. [42]. They described about how to change depth temporally. If stereoscopic HDTV images were moved in depth according to a step pulse function, visual fatigue was induced.

6. Visual fatigue and changes in oculomotor balance

If the discrepancy is small, the accommodation and convergence systems respond correctly, i.e., differently. It is often said that, this is unnatural, results in visual stress and causes visual fatigue. Some investigators, e.g., Howarth [43], have discussed how subjective symptoms changed when subjects viewed images with various discrepancies between accommodation and convergence. The results showed that subjects’ heterophoria changed along the changes in discrepancy, and that only small subjective changes were reported. In contrast, Yano et al. [42] have indicated that visual fatigue caused by watching stereo-

Fig. 7. Accommodative responses when viewing stereoscopic images depend on the target blur. (a) Average accommodative responses of five subjects. Responses to the stereoscopic images (3MA-2D) varied by the target blur. The figure is given by Okada et al. [37] with permission of the publisher. (b) Schematic drawing of the figure (a).
scopic HDTV images, that were displayed within the corresponding range of depth of focus, and remained motionless in the depth direction, was similar to fatigue induced by watching images displayed at screen depth. However, when images were displayed outside the corresponding range of depth of focus, visual fatigue occurred.

Aftereffects of accommodation and convergence demonstrate the adaptability of these two visual motor systems [44]. These aftereffects were reduced after exercises of either accommodation or vergence, and this reduced aftereffect or fatigue was associated with an increase of accommodative vergence and vergence accommodation. It was found that the majority of subjects with abnormal binocular vision and/or asthenopia lacked or had a deficient adaptation system to base-in and/or base-out prisms [45]. Prism vergences, heterophoria measurements, and the presence of fixation disparity gave little indication of the adaptation ability of the subjects. Symptoms correlated well with adaptation ability.

A number of studies have investigated the effect of stereoscopic images on various visual functions. In the case of conventional images, a change in binocular eye position with monocular fixation (phoria) may occur due to prism adaptation, convergence adaptation, or phoria adaptation [26,46], resulting from continuously viewing an object from a fixed visual distance. With stereoscopic images, an unnatural convergence load may bring these changes. Furthermore, there is also a phenomenon known as accommodative adaptation [47,48] that is of interest in relation to the progression of myopia. Interactions between accommodation and vergence system is indicated by accommodative convergence and convergence accommodation, quantified by the AC/A and CA/C ratios. They change following accommodation and vergence adaptations [27,49,50], and thus, the oculomotor balance might be changed by viewing stereoscopic images.

Accommodation is sometimes used as one of the few physiological indicators of visual fatigue, and thus is subjected to many types of measurements. Reaction velocity of step responses, especially velocity of disaccommodation, and amplitude of the response has been used as the main indicators of fatigue. Convergence limit and binocular vision are used when watching stereoscopic images [51] and how they change as result of forced convergence caused by fatigue is interesting.

Many studies have measured changes in these oculomotor functions before and after exposure to image loads, for various durations. Regarding stereoscopic images, Oohira and Ochiai [52] have examined phoria, fusional limit, AC/A ratio, accommodation, pupil activity and subjective symptoms before and after viewing stereoscopic TV images using the LC shutter system. No significant difference was found, although two aged subjects showed large changes in a few of these functions. Hasebe et al. [53] have investigated the AC/A ratio, binocular vision functions, convergence width, and refractory changes after using a stereo HMD for 25 min. Slight but significant hyperopic changes were detected in refraction after the task. Amplitude and velocity of convergence were varied significantly but inconsistently. No significant change was detected in the AC/A ratio and the stereo acuity. Howarth [54] has found that a mismatch between the inter-ocular distance (IOD) of bi-ocular/stereoscopic HMDs and user’s IPD is of little concern with distance heterophoria, however, the mismatch between the IOD of HMDs and the inter-screen distance may affect. Yano et al. [55] have measured visual fatigue using a subjective method and compared it to changes in accommodation before and after viewing images by stereoscopic HDTV. They reported that the mechanism mediating convergence eye movement and the accommodative function in depth of focus, as well as conflict of convergence eye movement and accommodative function, affected visual fatigue. Iwasaki and Tawara [56] have described the various aftereffects of accommodation and pupillary functions, that were dependent on the load distance, after a 10 min of viewing stereoscopic images of four viewing distances. Significant delay in the disaccommodation response was shown after the task in all viewing distances, but greater miosis was found only after far-distant viewing. Suzuki et al. [57] have examined accommodation step response velocity after 30 min of viewing stereoscopic images using the parallax barrier system. A significant slow down of average accommodation velocity was observed after viewing stereoscopic display but not after viewing non-stereoscopic display. The slow down depends on both the duration (15 or 30 min) of the viewing and the apparent distance (515 or 722 mm) between the viewer and the virtual objects. Emoto et al. [58] have found more serious subjective visual fatigue and decreased fusional amplitude in stereoscopic TV viewing than in viewing conventional TV. AC/A ratio showed no significant change in both viewing.

Other studies have investigated ocular–motor imbalance and visual fatigue when viewing non-stereoscopic images. After 4 h of VDU tasks [59], decreases in amplitude and the velocity of accommodation, delay and increase of the pupillary light reflex, and decrease in pupil size were reported. A weak correlation between the decrease in pupil size and accommodation function was found. Changes in various visual and oculomotor functions, such as refraction and visual acuity, tonic accommodation and accommodative velocity of step responses, distance and near heterophoria, AC/A ratio, following 2 h of viewing a movie using bi-ocular HMDs have been reported [60] that refraction change in both sphere and astigmatism was not systematic but the occurrence of the change greater than 0.38 D was increased, that accommodation did not change significantly, and that the eye position during fixating near target changed toward exophoria direction (AC/A ratio reduced). Kawara et al. [61] have studied eye movements and accommodation changes after 40 min of doing a virtual reality task with HMD. Both version eye movement and accommodative response became gradually slower during the 40-min task.
This slow down is suggested to be caused by the delay of image changes after head motion.

The findings of the studies reviewed above indicate that there are changes in oculomotor functions. However, the results of these studies have been inconsistent possibly due to different distance between the screen and the viewers, different pops up depths, different screen sizes, different load durations, different systems, and different image contents have been used. As a result, the differences in adaptation reported different studies might have been caused by differences in the experimental protocol. The most significant finding of the studies reviewed above has been that there could be a change in oculomotor balance caused by adaptation of the ocular control systems [30,49,44].

Irreversible changes in accommodation and convergence should be avoided by viewing stereoscopic images. Transient myopia related to visual fatigue, VDU work or stereoscopic images is often described [6,62] but this is equivalent to adaptation of accommodation. Irreversible change of accommodative functions such as onset of myopia, or its progression, cannot be examined without epidemiological study. One of such works [5] did not support any increased occurrence of myopia in the VDU workers compared with other near-vision workers while another [63] described increased myopic progression in the VDU workers. Viewing stereoscopic images is not so popular to carry out epidemiological study.

Some ophthalmologists remain concerned that viewing stereoscopic images may cause strabismus, an abnormality in binocular alignment, in young children. It is influenced by accommodation, vergence, and binocular vision. There is no evidence for or against the hypothesis that viewing stereoscopic images causes strabismus except for a report by Tsukuda and Murai [64]. They have reported a case of a 4 years and 11 month old boy who manifested esotropia after viewing stereoscopic animation at a cinema using an anaglyph. Photographs of the boy taken by his mother before and after viewing the stereoscopic movie helped in the diagnosis since the onset of the deviation of the eye can be clarified. After strabismic surgery, the patient kept orthophoria and binocular vision. Many ophthalmologists may not be aware that stereoscopic images are a cause of acute onset strabismus, and therefore, will not ask patients about such experiences. Because acute strabismus is often a sign of central nervous system abnormality such as brain tumor, or thyroid-associated ophthalmopathy [65], the exclusion of these causes should be a priory. Patients diagnosed as suffering from acute strabismus without any diseases may include those caused by stereoscopic images. von Noorden [65] described that one of the causes of acute strabismus is a disturbance of binocular vision, although almost all their examples were cases of monocular occlusion. Von Noorden [65] also noted that acute strabismic patients during infancy cannot explain their diplopia, and that some patients may recover spontaneously whereas others have to be surgically operated.

7. Changes in pupillary responses

Pupillary activities, such as pupil size, amplitude, and velocity of the responses to light, or other stimuli, are governed by the autonomic nervous system. Activity of the sympathetic nervous system increases pupil size and that of the parasympathetic nervous decreases it. Thus, pupil size reflects mental activity, as well as the whole body condition through the mediation of the autonomic nervous system [66]. Excitement, tiredness, sleepiness, and fatigue after viewing images can affect pupil activity. Furthermore, as one of the near triad, the pupil also reflects the oculomotor balance. Therefore, pupillary responses to light, as well as pupil size, are measured before and after a visual load. Pupillary adaptation to near fixation has also been reported [67,68].

The increased occurrence of pupillary hippus following near vision load has been reported in VDU workers [69]. Hippus is a slow (about once in 5 s), large-amplitude, cyclic changes of the pupil with strong constriction, induced by sleepiness in normal subjects and sometimes after near vision load [70]. Nakamura [71] also reported that subjects suffering eyestrain had smaller pupil size and a slow change of size. The intermittent light of CRT monitors reduced accommodative amplitude, increased eye blink interval, and made the pupil smaller [72]. In normal subjects, micro fluctuations of accommodation and pupil size were not significantly changed while working with displays [73]. Ando et al. [66] have compared the pupillary responses and cardiovascular parameters, which is another autonomic function, and has reported that the pupillary light reflex changed after viewing video movies in the low blood pressure group. Oyamada et al. [74] compared the effect of different types of stereoscopic movie on the pupillary response, as well as on subjective observations.

Recently, it was reported that a disparity was a strong enough stimulus for pupillary change to occur [75] regardless of convergence or accommodation.

8. Conclusion and future work

In this review, an overview of health issue related to viewing stereoscopic images was presented.

Viewers should be careful to avoid viewing stereoscopic images for extended durations because visual fatigue might be accumulated [57]. They should be ready to stop immediately if fusion difficulties are experienced. Hardware/software manufacturer should avoid unnatural image presentations, such as images that diverge further than infinity, large binocular disparity in the central visual field or around the objects that are the centre of the viewer’s attention, difference of size and colour, unequal distortion between binocular images since they may cause fusion difficulty.

Inter-individual differences in susceptibility are unclear. Fatigue may be a warning of serious damage to the human body by continuous exposure. Thus, severe damage may occur suddenly in those with lower susceptibility. One of
the many causes of differences in susceptibility is perhaps migraine. It is known that repetitive periodic spatial patterns are a cause of visual fatigue and migraine [2], which may also cause epileptic seizures in viewers with a diathesis [76]. Investigations of motion sickness in people with migraine has been well documented [77–79]. Pupillary functions in people with migraine has also been investigated [80]. It is suggested that in the future, the relation between susceptibility to stereoscopic visual fatigue and migraine should be investigated in more details.

Children should be cautioned about stereoscopic images because they may not subjectively perceive a problem even if an eye is deviated [65]. Although there is little evidence that viewing stereoscopic images causes irreversible damage to health, there is also no evidence that contradicts this contention. Ethically, it is not possible to conduct experimental studies using child participants, even although there is some evidence that visual/viso-motor functions develop up to the age of low teens [81]. Visual acuity, one of the most fundamental visual function, has plasticity up to 8 years old [65] or later [82]. Further, IPD of children is smaller than that of adults. IDP in 8 years child is about 54 mm [83]. Stereoscopic images designed to IPD about 60 mm have too large depth for children.

Finally, a question that the author is often asked regarding stereoscopic images is introduced. Myopia may progress with near work as accommodation adapts to a closer point in space. If this is the case, the question arises whether accommodating to a point further than the screen would be good for preventing the progress of myopia. The answer depends on whether stimuli discrepancy or strong accommodation is related to fatigue and myopia. If fatigue were caused by a discrepancy in accommodation and convergence stimuli, discrepancy would exist regardless of divergent stereoscopic stimuli. Conversely, if accommodation did play a role in fatigue, accommodating to a point further in space would be good for preventing myopia. However, given the state of current knowledge, in which the mechanisms of fatigue are unclear, it is not possible to state which theory would be most applicable. It may depend on the accommodative reserve of the viewers, i.e., on the age of the viewers.

Acknowledgements

This study was carried out under the Standard Authentication Research and development Programme, “Standardization of Assessment Method for Visual Image Safety,” promoted by the Ministry of Economy, Trade and Industry in Japan. This study was also supported by the Japanese Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Scientific Research (B), 16300034, 2004–2006, and 19300037, 2007.

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