Displays 33 (2012) 76–83

Contents lists available at SciVerse ScienceDirect

Displays

journal homepage: www.elsevier.com/locate/displa

Review

Visual fatigue caused by stereoscopic images and the search for the requirement to prevent them: A review

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ARTICLE INFO

Article history:
Available online 29 September 2011

Keywords:
Stereoscopic image
Biomedical influence
Guideline
Image safety
Binocular disparity

ABSTRACT

Recent literatures related to the evaluations of visual fatigue induced by stereoscopic images (VFSI) are reviewed with the short introduction of cortical mechanisms related to early visual processing, vergence eye movement and lens accommodation. Based on this knowledge, the requirements to prevent visual fatigue and discomfort induced by viewing stereoscopic images were sought. Firstly, the careful alignment in the right/left eye images is required for the stereoscopic vision without discomfort. Secondly, the conflict between the demands for vergence eye movement and lens accommodation in the near response should be avoided, by using modest binocular disparity. Thirdly, the frequency of changes in binocular disparity should be restricted. Finally, the appropriate viewing distance is also recommended to avoid visual fatigue.

Contents

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0141-9382/$ - see front matter
doi:10.1016/j.displa.2011.09.001

1. Introduction

Recently stereoscopic movies, TVs, and computer games became popular. In accordance with these trends, the necessities to establish a guideline which prevents undesirable biomedical influences have been widely recognized. Different from the serious symptoms as found in the cases of photosensitive seizures, the symptoms induced by viewing stereoscopic images, if any, are mostly within the range of severe discomfort or visual fatigue. However, in some cases, the symptoms continued even after cessation of viewing of stereoscopic images. With the accumulation of the accident reports related to stereoscopic movies, the National Consumer Affairs Center of Japan (http://www.kokusen.go.jp/nac_index_e.html) had the press conference at August, 2010 in the effort for people to pay attention to the potential risks they may have when viewing stereoscopic movies. They filed five cases, including severe headache and double vision even in a few days after viewing stereoscopic movies. Prolonged viewing of stereoscopic images or repeated exposures to them may accumulate physical changes underlying the symptoms to induce serious side-effects on health of these susceptible people. The accumulation of visual stress has been known in the visual display terminal (VDT) syndrome [48]. Although causality has not fully demonstrated, a case of esotropia after viewing an anaglyph movie has also been reported [83]. The efforts to prevent potential risks on health will be needed [24,87]. At present, one of the best ways to avoid these undesirable biomedical influences is to establish a guideline which recommends the conditions for comfortable viewing of stereoscopic images.

In this review, the factors related to discomfort or visual fatigue will be discussed to establish a basis for the sound and beneficial guideline for stereoscopic image safety, based on the subjective and objective evaluations. The knowledge on the mechanisms of early visual processing, and the crosslink between the control systems of vergence eye movement and lens accommodation is briefly introduced to facilitate understanding of the basis.

2. Visual cues for the stereoscopic vision and their cortical processing

Various cues for stereoscopic vision are known, including changes in size and brightness, chromatic aberration, geographical perspectives such as shapes and hidden lines of objects, and the distribution of shadows and lights [23,59,87]. The distance between a visual target and the viewer is not directly estimated by one simple measure, but it can be recognized by cortical processing of these various visual cues. Among these visual cues, the binocular disparity is most important, because it is controlled to provide stereoscopic images in the system available at present [79,87].

2.1. Binocular disparity and the initial visual pathway

Because of the distance between right and left eyes of about 63 mm [9], the images obtained from both eyes are slightly different, and this difference of view provides the cue for stereoscopic vision. The information from each eye is integrated in the primary visual cortex (the area V1), where each cortical cell receives various combinations of inputs from right and left eyes. Each of the V1 cortical cells has their own receptive fields in the region of the visual field allotted to them. The retina and the primary visual cortex have one to one geometrical relationship with the different magnification factor depending on the location of the retina. Light from the fixation point projects onto the fovea of the retina, where the color and precise shape of the object are sensed by densely packed visual cells. The information from the fovea projects to the wide central area of the area V1, through the lateral geniculate nucleus in the brain stem. The peripheral retina projects to the peripheral region of the area V1. Because of the densely packed cells of the fovea and high magnification in the central projection from retina to the area V1, the information of the central visual filed predominates, which is also essential to detect the binocular disparity.

2.1.1. Initial processing in the visual cortex

The initial processing in the visual cortex is understood in terms of three mechanisms to extract binocular disparities as follows; retinal disparity, positional disparity and motion disparity [62]. The retinal disparity is recognized as the distribution of the binocular disparity in the visual field which is reflected to the activities of cortical cells in the area V1 through the retina. In addition, cortical cells have been found in the striate and peristriate areas, which represent the positional disparity [60,61]. The cells tuned to around zero disparity (i.e., tuned zero excitatory or tuned inhibitory neurons) are activated by stimuli in the neighborhood of the fixation point, i.e., the Panum's fusional area [67], and depressed by nearer or farther stimuli. These tuned cells are also suppressed by the uncorrelated random dot stereogram. These neurons are then facilitated by stimuli around the horopter, and suppressed by stimuli in other depth. Other types of cells were activated by larger disparities, which may be responsible for the global stereopsis and the control of vergence eye movement. In addition, cortical neurons in the area V5 are activated by approaching or receding movement of the object [8,65], which may be responsible for motion disparity. The activities of the comparable cortical area are related to lens accommodation and convergence eye movement in animal experiments [1,80,81].

2.2. Global and fine stereoscopic structures

It has been known that we have two visual systems, i.e., the dorsal pathway which is related to the spatial vision, and the ventral pathway which is related to the shape and color vision. The global stereovision, which is related to three-dimensional arrangement in the global scene, or to the movement of an object, is innervated by the dorsal pathway [84], and the fine stereovision, such as the condition of the three-dimensional surface of the object is innervated by the ventral pathway [86]. Depth information is analyzed in both dorsal and ventral pathways, but the ways of processing may be different in each pathway [2,63]. In humans, it was found by the positron emission tomography (PET) that areas V1/V2 and V3