Effects of Stereoscopic Screen Disparity on Pupil Diameter

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***Abstract*—3D technology emerged as a new source of entertainment these days but unfortunately visual fatigue, headache and eyestrains have been reported by end users. A more severe effect is the development of Visually Induced Motion Sickness (VIMS). We hypothesize that VIMS is caused by rapid adjustment of the pupil diameter of the human eye. To test this hypothesis we have designed an experiment to observe effects of 3D stereoscopy on pupil diameter. The effect of stereoscopy is produced by generating disparities in the images, which cause the person to see depth in them. 3D induces a vergence accommodation response, producing changes in the pupil. We measured the changes in the pupil diameter caused by changes in the disparity of images. Results show that change in disparity causes a significant change in pupil diameter. This may be the cause of visually induced motion sickness.**

Keywords-Stereoscopy; VIMS; Disparity; Pupil Diameter; Vergence; Accommodation;

I. Introduction

Stereoscopy is a technique which adds depth to 2D images. This technique is now used by various display devices to create an illusion of depth in images. Stereoscopic images are produced using the same concept as how our eyes see. Eyes are a kind of camera, which have a sensor called retina that captures images. The left and right eyes capture two separate images, and the brain fuses the two images into a single image. Further processing is done in the brain to give a sense of distance of depth to the object that is being seen by the eyes.

Devices with stereoscopic view can be made in a number of ways. Generally stereoscopic TVs are color multiplexed, time multiplexed or polarization multiplexed [1]. Each of the techniques can produce stereo vision. The stereoscopic devices stated above require an eyewear that supports the corresponding technology. Other types of stereovision are head-mounted and auto stereoscopic displays. A complete discussion of stereovision techniques is out of the scope of this paper and interested readers can refer to related review papers [2-4].

Recently, people have reported feelings of eye strain, headache and nausea after watching 3D movies in the cinema [5]. This problem is commonly known as Visually Induced Motion Sickness (VIMS). People have reported feeling discomfort or visual fatigue while watching or after watching stereoscopic movies or images [1, 6, 7].

Many researchers started to look at the functional changes in the human body, which could possibly occur while watching 3D stereoscopic images or videos. They proposed a number of measurement tools to evaluate the symptoms, either subjectively or objectively. The most common subjective evaluation of VIMS used is the Simulator Sickness Questionnaire (SSQ). This questionnaire was the first used to assess simulator sickness, but have also been used for VIMS because the symptoms of both are almost the same [8].

On the other hand, objective indicators proposed for the observation of VIMS is based on autonomic responses of the body. In [9] the heart rate variability is used to measure mental stress. It is an index used to find parasympathetic and sympathetic nerve activity. In another work [10], it has been reported that sympathetic nerve activity is higher when viewing a 3D stimulus compared to a 2D stimulus. They have also compared the SSQ results with objective index measured. The results report that, 3D image viewers rated higher scores for SSQ.

Eye tracking is one of the latest indicators used in the evaluation of visual fatigue. It is mainly based on the activity of visual responses. It can track the movement of the eyes and record pupil diameter. Researchers have reported that a commercially available eye tracker can be used for measuring vergence response. It is reported that vergence response is more active in viewing of disparity images [11]. A detailed description of these visual responses will be discussed in the next section.

The rest of the paper is organized as follows. Section II gives a background on how the eyes function in normal viewing and in the 3D stereoscopic environment. Section III discusses the methodology of the investigation, followed by results presented in section IV. Finally we conclude and propose future work in section V.

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II. Background

A. Natural Viewing of Eyes

This subsection is based on [12].

The pathway in the brain that controls the pupil diameter is presented in the Figure 1. Naturally eyes view a 3D world by nearly two dimensional lens but mutual working of two eyes and complex processing of brain makes it possible for us to make perception of objects in 3D. An eye has millions of Rods and Cones cells, positioned in the retina, used to visualize the world. When a light ray reflected from an object falls on these cells, it stimulates them to produce a signal which is transmitted to brain. The amount of light entering the eye is restricted by the pupil. The pupil is controlled by a muscle called the iris.

When excessive amount of light enters the eye, retinal cells send a signal through the parasympathetic nerve III i.e. the optic nerve. Signal is transmitted to pretectal nucleus, which is located in the mid brain. Pretectal nucleus makes a synapse with Edinger-Westphal nucleus. From this nucleus signal is transmitted to ciliary ganglionic cells located just behind eyes. Activation of these cells constricts the iris, which in turn constricts the pupil.

When eyes shifts focus from a faraway object to a nearby object, two processes simultaneously take place - vergence and accommodation. Vergence is the inward or outward movement of the eye balls to look at a single point in space. When the eyes see a near object they converge (inwards movement) and when they are focused on a far object they diverge (outwards movement). Accommodation is a process in which the lens adjusts itself to focus the light beams on the fovea. If the eyes produce vergence, accommodation will spontaneously take place. The accommodation in the lens is brought into action by the ciliary muscles that are controlled by the same parasympathetic nerve.

B. Stereoscopic 3D (S3D)

Stereoscopic 3D is produced by fusing two images with a distance between them, known as disparity. Disparities are of two types, positive or uncross disparity and negative or cross disparity. Uncross disparity makes an object appear at the back of screen and cross disparity makes an object appear in front of the screen [13].

C. Eyes in Stereoscopic Environment

Stereoscopic displays are a little bit different from natural viewing. In these displays a person is trying to see 3D objects displayed on a 2D plane. This alters the vergence-accommodation response. Disparity in stereoscopic images causes the eyes to look at different images thus fixating on different points. This causes a change in the vergence response. Let's take an example, If the point of fixation are apart from each other i.e., images are having uncross disparity, they switch from uncross to cross disparity. Now this will cause the eyes to converge to a new focus point. This activation of vergence response also activates accommodation response, causing the lens to change its focus. Vergence shifts the focus of eyes on to a new plane.

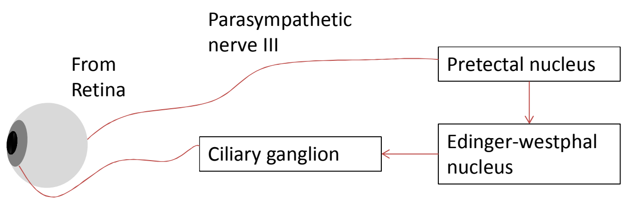

Figure 1. Neuronal Pathway of pupillary light reflex

Focus should be again set onto the screen plane as the objects are displayed over it. This process creates a conflict in the visual system which is commonly called as vergence-accommodation conflict. This is one of the major causes of discomfort in 3D [14].

Now, from the previous example vergence response activates accommodation of the eye. The parasympathetic nerve that produces accommodation response is also responsible for controlling the pupil diameter. Thus when accommodation occurs there is also a slight change in the pupil diameter.

III. Methodology

Based on this concept, we designed an experiment to find the changes in the pupil diameter while watching S3D. We hypothesized that due to the changes in disparity of stereoscopic images there should be a change in the pupil diameter.

A. Stimuli

45 images with disparities changing from cross to uncross were displayed. The images were rendered on 3D Studio Max. Images were composed of off-white background and a red ball in the center. Each image was displayed for three seconds.

B. Disparity in stereoscopic images

The sample stereo image is shown in Figure 2. Disparity between the two points of focus is calculated by subtracting the point in the two images. The disparity ranges from -116 to 32. Change in disparity of the images is given in the Figure 3. Negative disparity values are gradually increasing and moving towards positive disparities. This gradual change is due to the model which was made to take pictures in 3D studio max. A 3D stereo camera rig was made which was adjusted to take left and right images with cameras at a distance of 2 feet. The images were taken with a change in

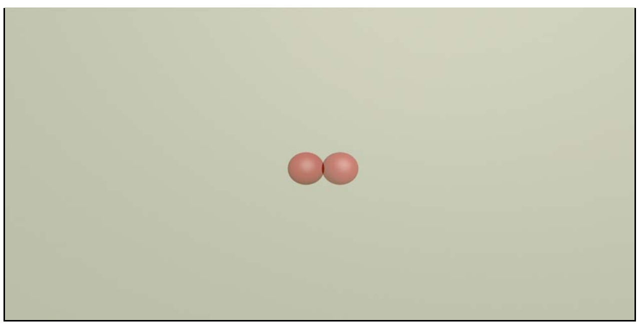

Figure 2. Sample interlaced stereoscopic image

focus of stereo rig with a step distance of 1inch. Therefore, initial change in the disparity is high and later the cameras move into parallel vision, thus decreasing the change in disparity.

C. Participants

Eleven (11) healthy participants (all males with average age of 25 years) took part in the experiment. All had normal vision or corrected to normal vision. Data from two participants was discarded in the final analysis because it was less than 75% with respect to total recording time.

In the experiment, participants were asked to look at the red ball at the center of the screen. Clear instruction was given to all participants to not move or shift their gaze from the ball. The restriction was imposed so that no external movement of eyes could cause a change in pupil diameter. The data for each image was composed of 1500 samples. Samples for each image were averaged giving only one value. This gives a total of 45 samples for each participant.

D. Equipment

Images were displayed on a 40” 3D LCD TV with a resolution of 1920x1080 pixel. The technology of this TV requires polarized glasses to generate 3D stereoscopic vision. Pupil data was recorded using a Tobii TX300 eye tracker. Sampling rate of eye tracker was set at 300 Hz. Binocular gaze accuracy of the eye tracker is 0.4 degrees.

E. Analysis

The data from the eye tracker software was exported for analysis and preprocessed in MATLAB for extracting the pupil diameter for each image. From there it was exported to IBM SPSS for final analysis. The data was analyzed by simple linear regression model to find the relationship between pupil diameters which is dependent on disparity values that are independent. The confidence interval was set at 95%.

IV. Results and Discussion

Results from simple linear regression analysis show that

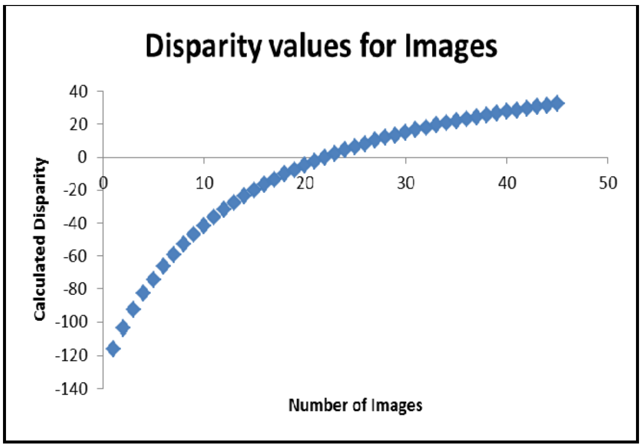

Figure 3. Disparity values for stereoscopic images

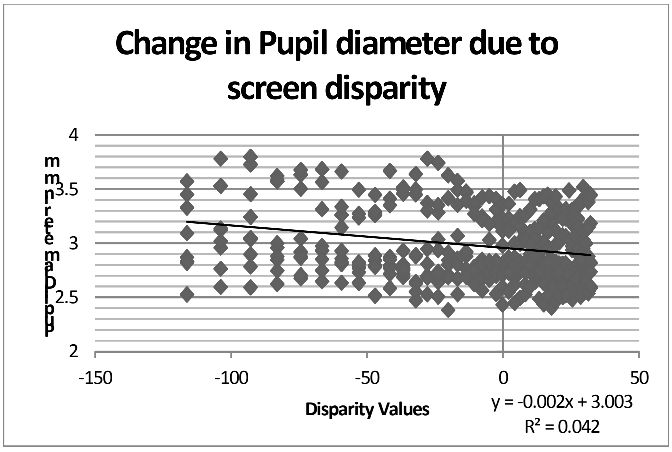

Figure 4. Results from simple linear regression

there is a significant relationship between disparity of stereoscopic images and pupil diameter. With the change in screen disparity from uncross to cross, the pupil diameter decreases. The results are still significant with a p value of less than 0.001. The results are displayed in Figure 4.

(b = -0.002, 95% CI, -0.003, -0.001, $p<0.001$)

According to linear regression model ($r^2 = 0.042$), Four percent (4%) of the variation in pupil diameter is because of the change in disparities of the stereoscopic image. Statistical results are presented in table 1.

The variation in pupil diameter depends mostly on light and sometimes from emotion. It has been reported that pupil restricts in bright light and dilates in low light. Thus reaction of pupil to light between participants can be very high or low. The luminance in the experiment was kept constant to minimize the effect of light on pupil diameter. Also the image was not composed of any 3D scene that can evoke emotional changes minimizing the effect of emotions on the brain. Efforts were made to have minimum effect of factors that can cause change in pupil diameter.

From [15] it is observed that pupil diameter values at a given illumination can have a range of 1.5mm. Here the range can be defined as a difference between maximum value of pupil diameter to the minimum value of the pupil diameter. For example at illumination of 1 mLambert smallest pupil recorded is 4.5mm and largest 5.8mm. Therefore, inter participant difference cannot be excluded from the study. This difference can be seen in Fig. 4.

TABLE I. RESULTS OF THE REGRESSION MODEL

Coefficients *					
Model	**Unstandardized Coefficients**		**Standardized Coefficients**	***t***	***Sig.***
	B	***Std. Error***	***Beta***		
(constant)	-3.003	0.019		156.673	0.001
Disparity values	-0.002	0.000	-0.205	-4.212	0.001

Model	**95.0 % Confidence Interval for B**	
	Lower Bound	***Upper bound***
(Constant)	2.965	3.041
Disparity Values	-0.003	-0.001

* Dependent Variable: Pupil diameter in millimeter

V. CONCLUSION AND FUTURE WORK

From the result of simple linear regression shows a significant decrease in pupil diameter with increasing disparity. From this result it is concluded that stereoscopic images produce the vergence accommodation response. In the experiment the depth changes after 3sec but in case of movies with 60 frames per second depth changes rapidly. If the images are changing with high disparity it can be a potential cause of producing eye strain in the people. This eye strain can accumulate further into a form of headache, as there is a high activity on the brain for sending signal to change the lens power of the eyes repeatedly. These kinds of indexes are the simplest measure of visual responses. The higher activity of such response could be a result of extra load on the mental activity.

The model for the experiment can be further enhanced to find the changes in cortical brain regions. Neuronal pathways of eyes link to primary visual cortex. When vergence response takes place, at the very same time movements of eyes i.e. voluntary and involuntary fixations are also taking place. Processing of eye movement is done in the cortical regions of brain.

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