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Using electromyography responses to investigate the effects of the display type, viewing distance, and viewing time on visual fatigue ☆

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ABSTRACT

The rapid success of 3D display technology and daily accessibility to 3D images has greatly increased the interest in such applications for a wide range of fields. This paper compares the effects of watching movies with 2D and 3D displays depending on the viewing distance (3H vs. 6H, where H is the height of the screen) and viewing time to determine the visual fatigue using electromyography (EMG) in terms of the percentage of maximum voluntary contraction (%MVC) of the orbicularis oculi (OO) muscle activity and a subjective visual discomfort score. Twenty healthy male university students with a mean age of 27.7 ± 2.53 years participated in this study as volunteers. None had color blindness, and all had normal vision acuity. A mixed-measures design was performed. The results showed that the viewing time and distance had significant effects on the %MVC and OO muscle activity depending on the display type. Watching the 3D display from a short viewing distance produced significantly high visual fatigue compared to watching the 2D display from a short viewing distance. However, the 3D display seemed to be less stressful than the 2D display at long viewing distances.

1. Introduction

Rapid success and daily accessibility to 3D images have increased the applications of 3D display technology. The use of 3D stereoscopic images has garnered great interest and increased their application in geospatial studies, advertising, oil and gas drilling, entertainment, education, medicine, industrial design, scientific research, training, defense, etc., as an alternative to 2D display images [1]. Despite numerous benefits, 3D screens also have adverse effects, such as visual fatigue and changes in heart rhythm [2–4].

Visual fatigue is a critical issue because 3D displays can cause a great deal of discomfort in humans [5,6]. This issue has received a great deal of attention from the research community. Various visual fatigue symptoms are due to abnormal viewing conditions and may include eyestrain, headaches, dried mucus or tears around the eyelids, aching around the eyes, a pressure sensation in the eyes, nuisance when the eyes are open, difficulty with focusing, and shoulder pain [7,8].

The causes of visual fatigue are very diverse, so they are still under research. With video terminal displays (VTDs), visual fatigue is caused by vision abnormalities like vergence inability and accommodative dysfunction. In addition, visual fatigue may be caused by display issues such as suboptimal gaze angles, compromised image quality, flickering stimuli, display technology, and environmental conditions [9–12]. The viewing time and distance are significant contributing factors to the visual fatigue associated with 3D displays [10,13,14]. The viewing distance is considered as an essential environmental condition and is described in the guidelines for VTDs [13]. Park and Mun [15] showed that discomfort due to negative and positive conflicts in binocular disparity depends strongly on the viewing distance. Prolonged viewing of a 3D display also increases the degree of visual fatigue [10,16]. Emoto et al. [17] presented images at the distance of 1.2 m and Yano et al. [18] used a visual distance of 1.08 m, corresponding to 3H. Matthews [19] studied the long-term effects of visual fatigue from watching chromatic displays. The American Optometric Association [20] found that prolonged use of visual systems can result in inefficient visual processing functions, which they considered visual fatigue.

Because visual fatigue has several contributing factors and symptoms, there are several measurement methods. Reliable measurement methods that can quantitatively evaluate 3D visual fatigue are still under research. Several studies have been conducted to evaluate visual fatigue by using subjective ratings and physiological evaluation methods. The latter includes event-related

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potential (ERP) signals, electroencephalogram (EEG), electrooculography (EOG), functional magnetic resonance imaging (fMRI), electrocardiography (ECG), critical flicker fusion (CFF), near-point accommodation (NPA), visual evoked cortical potentials (VECP), steady-state visually evoked potentials (SSVEP), near-infrared spectroscopy (NIRS), galvanic skin response (GSR), heart–brain synchronization, and skin temperature (SKT) in a 3D display environment [6,21–40]. With the expansion of the 3D display industry, the safety of 3D displays needs to be thoroughly examined and verified. Previous studies on objective responses to viewing display images only compared measures recorded in pre- and post-watching periods. Objective responses during viewing of the display have been neglected, except for one study by Kim et al. [5]; they used GSR, ECG, and SKT to measure the visual fatigue during a viewing period of 1 h.

Electromyography (EMG) is a technique for measuring the electrical activity generated by skeletal muscles. The EMG signal is an electrical current produced by muscles as they contract and represents neuromuscular activity [41]. EMG is the most commonly used tool for recording muscle activation and fatigue. Variations in EMG activity (e.g., an increase in EMG amplitude) during consistent voluntary contractions are frequently used as indicators of muscle fatigue [42]. Gowrisankaran et al. [42] evaluated the contribution of increased cognitive load (with or without visual stress inducing conditions) to asthenopic symptoms associated with prolonged near work using blink rate obtained by record the electromyography potentials from the lower orbicularis oculi muscle.

Berman et al. [43] showed that EMG recordings from the orbicularis oculi (OO) are a sensitive measure of discomfort resulting from glare. Gowrisankaran et al. [44] studied the orbicularis oculi muscle response to asthenopia-inducing conditions using surface electromyography (EMG). Gowrisankaran et al. [42,44] found that visually stressful conditions due to a reading task increases EMG activity from the OO.

Nahar et al. [45] determined the sensitivity of the electromyography (EMG) response of the orbicularis oculi muscle to selected lower-level visually stressful conditions in order to establish the extent to which it can be used as a measure of visual discomfort. Also, Nahar et al. [45] pointed out that the EMG response is a good sensitive objective measure for graded levels of stressful visual conditions. Yoo [46] used EMG to compare the orbicularis oculi muscle activity during computer work with single and dual monitors and to evaluate tension in the muscles surrounding the eyes.

In the available literature, no single study has considered the relationship between OO muscle activity measured by EMG and the visual fatigue generated from 3D displays. This study investigated the effects of the display type, viewing distance, and viewing time on the visual fatigue based on the percentage of maximum EMG contraction (%MVC) of OO muscle activity and a total subjective visual discomfort score.

2. Methods

2.1. Experimental design

Four independent variables were considered: two involved repeated measures, and the other two were binary variables. Thus, the mixed design (i.e., $A \times B \times (C \times D \times S)$) could be used to represent the experiment. The two independent binary variables were (A) the display type (2D vs. 3D) and (B) viewing distance (3H vs. 6H, where H is the height of the screen). The two independent variables based on repeated measures were (C) movies (Avengers, Jurassic World, San Andreas, and Godzilla) and (D) viewing time (pre-test, T10, T20, T30, T40, T50, T60, and post-test). This experiment examined the influence of the viewing distance and display type in a repeated experiment based on the session time. Thus, it was a $2 \times 2 \times 4 \times 8$ design. Each of the (A) and (B) = $2 \times 2 = 4$ display–distance conditions contained S = 5 participants, and each participant watched all four movies. All physiological measurements were continuously taken starting at pre-test (3 min prior to the experiment), T10 (first 10-min period), T20 (second 10-min period), T30 (third 10-min period), T40 (fourth 10-min period), T50 (fifth 10-min period), T60 (sixth and last 10-min period), and post-test (3 min period after the experiment). Pairwise comparisons were used to investigate the source of any significant effects regarding the time factor.

2.2. Participants

Twenty healthy male university students with a mean age of 27.7 years and standard deviation of 2.53 years participated in this study as volunteers. Three were awarded partial credits from their class professor. A written informed consent form approved by the Human Participants Review Sub-committee of the Institutional Review Board (IRB) of King Saud University, College of Medicine, and King Khalid University Hospital was completed by each participant before they participated in the experiment. All participants had normal vision acuity, and no one had any medical history. Before the experiment, all participants were instructed to get a full night of rest and avoid cigarettes and caffeine for 6 h prior to the experiment. During the test, they were instructed to avoid moving their hands and head as much as possible. Table 1 presented the demographic and vision data.

2.3. Equipment

The equipment used in this study included a commercial 50-in. LG 3D Smart TV (50LF650T) with passive 3D glasses. In addition, an 8-Channel Biomonitor ME6000 (Mega Electronics Ltd., Kuopio, Finland), with two channels for EMG recording, a Snellen chart, GPM Vernier calipers, measuring tape, a visual discomfort questionnaire (VDQ), and neurophysiological and cardiovascular assessment were used to gather general information history. The software system used to record signals was Mega Win 3.0.1 (Mega Electronics Ltd., Kuopio, Finland). Raw materials included 70% isopropyl alcohol swabs, cotton squares, bandages, and Ag/AgCl solid adhesive pre-gelled electrodes for EMG (Ambu A/S, Denmark).

2.4. Experimental setup

The 2D and 3D movies were displayed on a commercial LG 3D Smart TV (50LF650T) using passive row interlaced technology. Table 2 presents the main specifications of the system. The LG TV was positioned at a height of 0.96 m, and the center of the display height was 1.29 m from the lab floor. The viewing distances were set at 1.95 and 3.90 m (3H and 6H). In Park et al. [47], the viewing distance was set at 3H, where H is the height of the screen (50 cm), as per the recommendations for 3D safety (3–6H) [48]. However, in Park et al. [49] study, the viewing distance was set to six times the height of the display. Therefore, the experiment was performed under two conditions of viewing distances, 3H, and 6H where H is the height of the display. The reason for selecting the three times and six times of the display height was mainly based on the recommendation in the International Telecommunication Union (ITU) standards [48]. The background distance from the screen to the wall was 0.12 m. To avoid any disturbance to the participant's surrounding, black sheets were pasted on the wall around the TV, as shown in Fig. 1.

All experiments were conducted in the Human Factors Lab with an average dry-bulb temperature and relative humidity of 23.8 °C and 30.6%, respectively. The experimental zone was ensured to