Displays 33 (2012) 84–90

Contents lists available at SciVerse ScienceDirect

Displays

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

Reading performance as screening tool for visual complaints from stereoscopic content

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ARTICLE INFO

Article history:
Available online 20 March 2012

Keywords:
Visual discomfort
Visual fatigue
Reading performance
Objective and subjective measurement
Screening tool

ABSTRACT

Some people experience visual discomfort when watching stereoscopic content, which to a large extent can be predicted by their binocular visual status. Earlier research has proven that the binocular status can be assessed by the difference in reading speed between 2-D and 3-D. In this paper, we further substantiate the evidence for a tool to screen people on their susceptibility to such visual complaints based on this reading speed difference.

In an experiment participants were asked to (1) perform the Wilkins Rate of Reading Test (WRRT) at three disparities (−1.5°, 0° and 1.5°) preceded and followed by fusion measurements and self-reports, and (2) scale the screen disparity of stimuli to a threshold of visual discomfort. Participants were categorized based on the WRRT-ratio, being the ratio of the number of words read at 0° disparity over the number of words read at −1.5° disparity.

Our results showed that only participants with a high WRRT-ratio revealed a tendency in changed fusion range indicating visual fatigue. They also reported significantly more visual discomfort in stereoscopic conditions and had lower thresholds in screen disparity for visual discomfort than participants with a normal WRRT-ratio. Hence, the WRRT-ratio has potential as a visual screening tool in 3-D consumer applications to warn viewers that are susceptible to visual discomfort when watching stereoscopic content.

1. Introduction

Stereoscopic movies boost the viewing experience by rendering content in front of or behind the display plane, yet numerous studies have reported the possible occurrence of visual complaints [1–15]. These visual complaints are not experienced equally by all people because of differences in the binocular visual system of individuals [1–4]. Very useful in that respect, is a visual screening tool that identifies viewers who are susceptible to visual complaints while watching stereoscopic content. With such a tool viewers can be warned for potential adverse visual effects or they can adjust their screen disparity to ensure a comfortable viewing experience.

Although the binocular system of viewers without some form of a binocular anomaly [3–5,16] is often characterized as normal, it may still show individual variation. Some of these viewers may not experience visual complaints in normal viewing situations, but may do so in unnatural viewing conditions, such as viewing stereoscopic content. Their binocular system permits stereopsis, but may predispose the viewer to visual complaints and headaches while viewing stereoscopic content. Approximately 10–20% of patients consulting community optometrists is affected by such visual problems [16], though somewhat higher percentages have been reported as well [17–22]. The relatively large size of this group justifies the development of guidelines and norms that enable comfortable viewing of stereoscopic displays, taking the binocular functioning of individuals into account.

Lambooij et al. [3,12] have proven that the binocular status, established by an optometric screening algorithm constructed by Evans [23], can be assessed by the difference in reading speed between a 2-D and 3-D condition of the Wilkins Rate of Reading Test (WRRT) [24]. The number of words read in 2-D divided by the number of words read in the crossed 3-D condition (WRRT-ratio) was demonstrated to be significantly higher for people with a moderate binocular functioning than for people with a good

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0141-9382/$ - see front matter © 2012 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.displa.2012.03.002

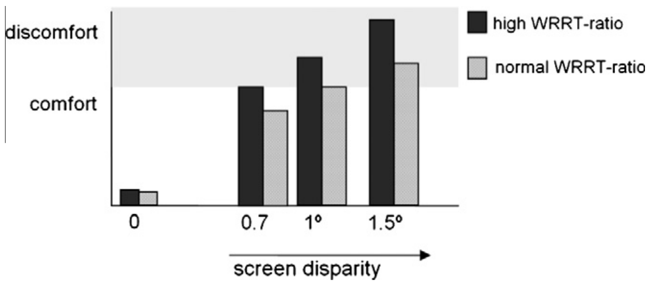

Fig. 1. The hypothesized relationship between WRRT-ratio, screen disparity and visual discomfort.

binocular functioning. This criterion had a 93% specificity (ability to correctly identify people without a specific condition), an 83% sensitivity (ability to correctly identify people with a specific condition), and a high sensitivity index of 2.4 [4], when using the Evans optometric screening as a reference. In this paper, the aim is to further substantiate the evidence for the applicability of the WRRT-ratio as a screening tool to indicate people's susceptibility to visual complaints as a consequence of viewing stereoscopic content.

Our first objective is to investigate whether the WRRT-ratio is a proper measure to predict visual fatigue and visual discomfort. We hypothesize that participants with a high WRRT-ratio indicate more visual fatigue and visual discomfort than those with a normal WRRT-ratio. The combination of fusion range measurement and self-report is used to measure visual fatigue and visual discomfort [3]. The distinction between high and normal WRRT-ratio is based on the criterion of one standard deviation away from the mean WRRT-ratio, as established in our previous research [3,4]. The second objective is to investigate whether the threshold in screen disparity for visual discomfort directly relates to the WRRT-ratio. We hypothesize that higher disparities generate more visual fatigue and visual discomfort for people with a high WRRT-ratio than for people with a normal WRRT-ratio, as visualized in Fig. 1.

2. Methods

2.1. Experimental design

We chose for a within-subject experimental design that consisted of two parts. In the first part, the WRRT was performed under three different screen disparity conditions (Disparity): −1.5°, 0° and 1.5°, where '−' refers to crossed screen disparity. A different WRRT page was assigned randomly to each screen disparity condition, and the order of the screen disparity conditions was randomized across participants. Each WRRT was preceded and followed by an objective fusion range measurement and a subjective questionnaire. In the second part (hereafter referred to as tuning experiment), the screen disparity of five stereoscopic stills (Image) was tuned to a threshold of visual discomfort for both crossed and uncrossed screen disparity.

2.2. Participants

Thirty-three subjects, employees as well as students working in a university environment, participated. Eight were male and 25 were female; they had a mean age of 23 years (range between 19 and 34 years). Only young and visually healthy participants were included; those with eye diseases or severe binocular abnormalities such as partial (stereo) blindness, large refractive errors (>0.50 diopter (*D*)), strabismus and amblyopia, were excluded. All had a good visual acuity of ⩾20/20 (6/6) (tested with the Landolt C-test) and a good stereoscopic acuity of ⩽30 arc seconds (tested with the RANDOT stereo test).

2.3. Stimuli

2.3.1. WRRT stimuli

The stimuli in the first part of the experiment consisted of three different passages of the Wilkins Rate of Reading test (WRRT) [24] that were randomly assigned to conditions. The WRRT consists of a meaningless passage of seemingly random words; ten lines with on each line the same 15 words distributed randomly (e.g., "you for the and not see my play come is look dog cat to up"). Since common simple words are used also poor readers can perform the task. The text is independent of any syntactic and semantic constraints and because participants do not know which word comes next this requires them to keep the text in focus. Another consequence of its meaningless character is that readers do not have a sense of failure when making errors. Participants were asked to read 'out loud' the WRRT as rapidly as possible for 60 s.

Fig. 2 depicts a screen shot of a stimulus. Since stressing the visual system is the simplest way to evaluate its relationship with asthenopia, screen disparities up to a maximum of 1.5° were used [3,4]. Only the text was presented with stereoscopic depth, whereas the frame with the circles was presented at zero disparity. The frame was added around the periphery to improve the perception of stereoscopic depth and facilitate faster and easier fusion. The visual angle of the text, inner and outer frame were 6.45°, 10.08° and 11.53° in horizontal direction and 3.17°, 3.69° and 5.67° in vertical direction, respectively.

2.3.2. Tuning stimuli

Five stimuli were used in the tuning part of the experiment: a version of the WRRT and four still images depicted in Fig. 2. The horizontal and vertical visual angle of all four still images was 6.93° and the text in the upper part of the image *Search* had a vertical visual angle of 1.61°. Two of these images, *Search* and *Labyrinth*, facilitated a task that required participants to keep the stimuli fused and in focus for a requested minimum period. The image *Search* was presented in two versions: one in which the image plus the text could be tuned in terms of screen disparity and one in which only the objects could be tuned in screen disparity. The latter version forced participants to switch perception continuously between the 2-D text and the 3-D objects. The *Medical* image was incorporated since it contained a high level of detail. The *Bureau* image contained relative stereoscopic depth, i.e., stereoscopic depth within the image. This stereoscopic depth was created with a stereoscopic studio camera in a toed-in configuration with a convergence distance of the cameras of 1.30 m and a base distance of 80 mm. All other stimuli contained no relative stereoscopic depth, i.e., the left- and right eye image were equal and rendered with a fixed translation (i.e., disparity) with respect to each other.

2.4. Measurement methods

The WRRT-ratio is defined as the number of words read in 2-D divided by the number of words read in the crossed 3-D condition (i.e., when the text is 1.5° closer to the participant) [3,4]. A WRRT-ratio is chosen to be high (i.e., HWRRT-ratio) if it deviates more than one standard deviation from the mean over all participants (for more detailed information see [4]). Note that a HWRRT-ratio indicates a worse reading performance than a normal WRRT-ratio (i.e., NWRRT-ratio).

The objective impact of the stereoscopic stimuli on the binocular visual system is evaluated with pre-post-measurements of the fusion range, which are proven to be a proper indicator for visual