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Assessing stereo blindness and stereo acuity on digital displays

Davide Gadia [a,*], Gianfranco Garipoli [a], Cristian Bonanomi [a], Luigi Albani [b], Alessandro Rizzi [a]

[a] Department of Computer Science, University of Milano, Via Comelico 39, 20135 Milano, Italy
[b] FIMI – a BARCO Company, Via Saul Banfi 1, 21047 Saronno, Italy

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ABSTRACT

Previous studies on stereoscopic acuity have shown that the percentage of stereo blind subjects is relevant. Moreover, stereoscopic visualization is becoming widely diffused in different fields, like, e.g., entertainment, surgery or VR training, where it is necessary an accurate assessment of stereoscopic abilities of the involved subjects. Therefore, there might be the need of performing a stereo blindness and stereo acuity test before each visualization session involving stereoscopic images. In this paper, we propose a method to assess stereo acuity and stereo blindness directly on the chosen device, under the same visualization condition and setup adopted for the tasks to perform, in order to have the same perceptual response. We present software-based tests suitable for a generic stereoscopic displays, and we compare their effectiveness performing a comparison with a standard physical, card-based, test commonly used in assessment of stereo acuity and stereo blindness. We provide to the reader all the details to perform autonomously the tests, of which images will be downloadable from web.

1. Introduction

In the recent years, the interest for stereoscopic visualization is growing rapidly in all the fields of research and application [1], thanks to the introduction of new hardware and software solutions.

In literature, we can find numerous sources covering the technical background of stereoscopic acquisition, visualization and printing [2,3]. Particular attention has been given to the issues related to perspective and geometric analysis [4], calibration and correction of stereoscopic acquisition systems [5,6], crosstalk in stereoscopic displays [7–9], and analysis and prevention of visual fatigue and discomfort [10–12].

Stereoscopy creates an illusion of depth by means of two images corresponding to different views of a scene. These images are sent to each of observers eye using specific hardware solutions. This simulates one of the major mechanism of human vision: most of the observers are able to process the differences between the two views (binocular disparity), elaborating the perception of depth (a process called stereopsis [13]). Observers with anomalies on this perceptual ability may have difficulties in combining correctly horizontal binocular disparities, and are called "stereoblind".

Different studies have demonstrated that the percentage of stereoblind observers is relevant. A survey [14] has shown that among 150 students at M.I.T., about 4% has been unable to use the cue offered by disparity, and another 10% had great difficulty and has reported incorrectly the depth of a Julesz random pattern test [13]. In [15] it is reported that 14% of users (359 on a set of 2520 subjects) has been unable to see depth at the largest stereoscopic disparity tested, 450 seconds of arc, and have been classified as stereoblind.

Other studies, performed on large sets of people, have investigated the relationship between age and stereopsis [16–19], or have been focused on children, where stereopsis is developing [20,21]. These works have demonstrated that, even if stereoscopic vision of older subjects is comparable to that of younger observers in many aspects, age-related differences in stereopsis do exist, and they become most noticeable when the stereoscopic ability of older subjects is challenged by multiple simultaneous factors. These works has shown also that the threshold of stereo acuity decreases with age [18,20]. Other works have investigated the presence or absence of stereoscopic ability without reporting the individual's level of depth discrimination [13]. In [22], the 97.3% of the considered population has been able to notice a depth difference at horizontal disparities of 2.3 minutes of arc

* Corresponding author. Tel.: +39 0250314001.
E-mail addresses: davide.gadia@unimi.it (D. Gadia), cristian.bonanomi@unimi.it (C. Bonanomi), luigi.albani@barco.com (L. Albani), alessandro.rizzi@unimi.it (A. Rizzi).

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or smaller, with at least the 80% able to detect depth differences at 30 seconds of arc.

Therefore, it is evident that testing stereo blindness and stereo acuity can be extremely important before a session involving stereoscopic visualization, in particular when stereoscopy is used in critical tasks, like, e.g. surgeries or VR training for risky tasks.

In most of the previous cited works, stereo blindness and stereo acuity have been assessed tested using well-known tests like the Randot, TNO, Titmus, Frisby, Lang II [23]. These tests, developed for clinical purposes by ophthalmologists, optometrists, and other eye care professionals and vision researchers, are based on printed cards with standardized symbols and patterns, and make use mainly of polarized glasses. Several works [19,24–27] studied and compared the validity and reliability of different stereo tests, coming to different conclusions about which test gives the most reliable results, or even debating on their actual effectiveness as screening tools. For example, in [19], all the subjects were able to achieve a stereo acuity of 3.3 minutes of arc with the Titmus test and 5.6 minutes of arc using the Frisby near stereotest. In a recent paper [27], the author states that random-dot stereograms are not the best possible choice for stereo blindness test, because their correct perception requires not only a correct stereopsis, but involves also other higher cognitive processes which initially require some time before a correct estimation. In other works, like in [28], improved versions of these kind of tests were proposed.

Starting from the experience in the design of the card-based tests, other scholars [29–32] have proposed computer based stereo blindness tests. Some examples of commercial products has been adopted widely, like the B-VAT II-SG system [33,34], a monitor-based system used for different visual acuity tests. Most of these products collected digital reproductions of the card-based tests, while others proposed improved or animation-based stimuli.

In general, those tests are implemented on dedicated systems, usually different from the devices used to accomplish the stereo task. In this way, the different conditions of stereoscopic visualization may lead to eventual different perceptual response. In fact, stereoscopic visualization depends on an accurate balance among different parameters, like, e.g. the initial disparity between the two stereoscopic views, the achievable parallax on screen due to resolution and dimension of the stereoscopic display, and the distance between the display and the viewer [2,3]. Even a subtle change in one of these parameters may affect the minimum representable depth or the minimum perceived depth.

For this reason, in this paper we propose methods to assess stereo acuity and blindness using the same visualization condition and setup adopted for the tasks to perform. Thus, it is possible to assess stereo abilities of the subject exactly with the stereo parameters used to accomplish the work. Therefore, there is the need for software-based stereo tests, installable and adaptable to the different possible visualization setups and devices. With respect to a physical test, a software-based test allows also a better control of parameters like luminance levels, which are much better controlled using a display, since the physical tests may suffer from varying and not optimal illumination condition, affecting the reliability of data, especially for small disparities.

In a preliminary work [35], we have proposed a first stereoscopic blindness test, inspired by similar stimuli adopted in physical tests. In this paper, we present the complete work, comparing the proposed software-based stereo blindness test (called *D_SB*) and stereo acuity test (called *D_SA*) with a physical test. In Section 2 we present a description of the physical test used as a reference for the proposed stereo assessment tests, and of the devices used during the experiments. In Sections 3 and 4 we describe the experimental procedures, the subjects involved and the obtained results from D_SB and D_SA software-based tests, compared to the corresponding stereo blindness and stereo acuity assessment methods present in the physical test adopted as reference. We conclude the paper with a final discussion in Section 5.

2. Apparatus

2.1. Physical stereo assessment test (Random Dot 2 Stereo Acuity Test)

We have considered the Random Dot 2 Stereo Acuity Test [36] for the comparison with the proposed software-based D_SB and D_SA stereo blindness and acuity tests. The Random Dot 2 Stereo Acuity Test uses polarized glasses. It consists of two different stereo blindness tests, together with one stereo acuity test. One of tests is aimed to children stereo assessment, and it has not been considered in this paper. The second stereo blindness test uses random-dot stereograms based on LEA Symbols® [37]. The test is composed by a 3 × 4 boxes grid, and in each row, three boxes contain a LEA Symbols® at a fixed disparity (500, 250 and 125 seconds of arc, respectively), and the fourth contains random dots only. Users must report for each box if they perceive an object at a different depth from the background, and they must identify the object shape.

The stereo acuity test is based on a graded circle test composed by 12 boxes, arranged in a 3 × 4 grid. In each box, three circles are depicted side by side, with only one circle placed at a not-null disparity. The set of disparities ranges from 400 to 12.5 seconds of arc. The circles are drawn using a black and thick border, and their background is a random dots pattern. Starting with the largest disparity in a descending scale, the subject is asked to identify the circle at each level that appears closer than the others. The last level for which the subject answers correctly is considered to be the level of stereoacuity.

The Random Dot 2 Stereo Acuity Test is shown in Fig. 1. The stereo blindness test is in the first page, while the stereo acuity test is in the first half of the second page.

Fig. 1. Random Dot 2 Stereo Acuity Test.