Investigating Visual Discomfort With 3D Displays: The Stereoscopic Discomfort Scale

Fabrizio Bracco
University of Genoa
Dept. of Educational Sciences
C.so A. Podestà, 2
Genoa, 16128 ITALY
fabrizio.bracco@unige.it

Carlo Chiorri
University of Genoa
Dept. of Educational Sciences
C.so A. Podestà, 2
Genoa, 16128 ITALY
carlo.chiorri@unige.it

Donald Glowinski
University of Genoa - DIBRIS
InfoMus Lab-Casa Paganini
Via Opera Pia, 13,
Genoa, 16145 ITALY
donald.glowinski@unige.it

Beatrice Hosseini Nia
University of Genoa
Dept. of Educational Sciences
C.so A. Podestà, 2
Genoa, 16128 ITALY
beatrice.hosseini@hotmail.it

Gianni Vercelli
University of Genoa - DIBRIS
Dept. of Informatics,
Bioengineering, Robotics and
Systems Engineering
Via all'Opera Pia 13
Genoa, 16145 ITALY
gianni.vercelli@unige.it

CHI'13 Extended Abstract, April 27 – May 2, 2013, Paris, France.
ACM 978-1-4503-1952-2.

Abstract
Notwithstanding their widespread diffusion, stereoscopic media have important drawbacks in terms of viewers' visual discomfort. Current assessment methods are mainly based on measures of objective parameters such as eye physiology or media characteristics. On the other hand, subjective methods only evaluate the personal experience related to the physiological symptoms. In this pilot study we developed and validated the Stereoscopic Discomfort Scale (SDS), a self-assessment tool for the subjective evaluation of physiological and psychological symptoms related to stereoscopic viewing. The results show evidence of internal consistency, unidimensionality and construct validity of the scale. Since SDS scores were also strongly correlated with facets of presence, we argue that the SDS could be a useful tool for the investigation of users' experience related to stereoscopic media.

Author Keywords
Visual discomfort; three-dimensional displays; self-report scale

Rationale of the 3D technology

The 3D technology is mainly based on binocular disparity, i.e., the slightly different horizontal perspective of the two eyes. In fact, the retinal image on each eye is different and varies according to distance. A 3D display implements this mechanism by providing slightly different views of the same object to the two eyes. This will allow the viewer to experience a sense of depth of the displayed scene, seeing objects as in front of behind the screen. With the negative screen parallax, the image on the screen is doubled and the left image is projected to the left eye, while the right one is projected to right eye. The viewer will see the object as standing in front of the screen. With the positive screen parallax, the right image is projected to the right eye, and the left image is projected to the left eye. The viewer will see the object as behind the screen (Fig. 1)

ACM Classification Keywords

H.5.2. Information interfaces and presentation. H.5.2 User Interfaces, evaluation/methodology

General Terms

Measurement, Experimentation, Human Factors

Introduction

Stereoscopic media have recently got a wide distribution and are generally well accepted by viewers. Three-dimensional (3D) movies have now overcome traditional ones (based on perspective-3D) in terms of tickets sales and in recent years electronics companies have begun producing entertainment devices based on the 3D technology (LCD panels, 3D tablets and smartphones) [1].

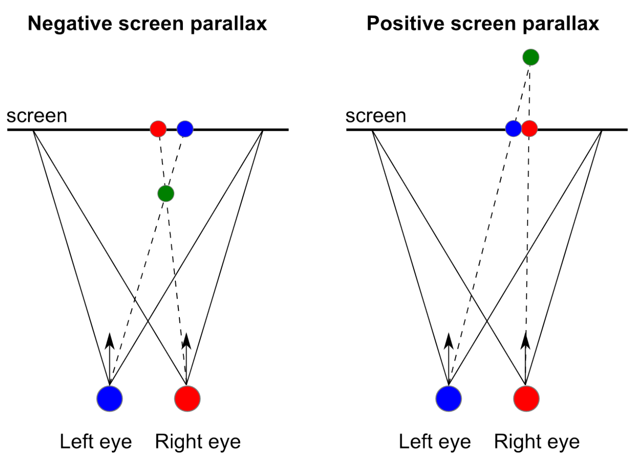

Figure 1. Basic description of a 3D display. The picture (green dot) will seem in front of the display it is presented with negative screen parallax. It will be perceived as behind the screen if presented with positive screen parallax.

The 3D technology enhances the sense of involvement of viewers and can provide a spectacular feeling of presence thanks to the enhanced realism of the displayed scene. Moviemakers take advantage of this kind of technology and adapt media contents to it, stimulating the immersion of the viewers in the narrated story. However, notwithstanding this worldwide success, the potential drawbacks of such a new technology cannot be ignored. One of the major problems encountered by viewers is visual discomfort [2-6], which can be framed it in the wider concept of asthenopia, or "weak eye" [8]. Asthenopia is a macro-category encompassing several symptoms that can be assessed through subjective and objective methods [2] (Fig. 2).

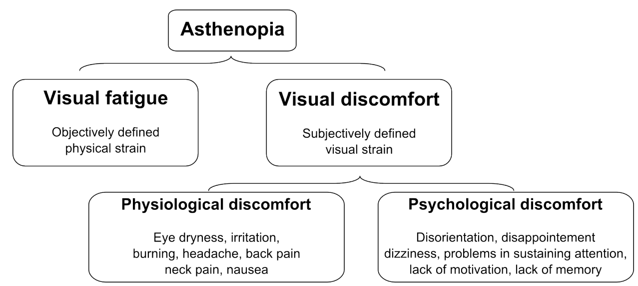

Figure 2. Asthenopia is measurable by means of objective methods (visual fatigue) and subjective methods (visual discomfort). The latter is based on the self rating of physical and psychological strain effects.

The objective assessment mainly deals with visual fatigue, which is a decrease in performance of the visual system. It can be measured by means of objective parameters such as eye dryness, eye accommodation, etc. The advantages of an objective

Main stereoscopic distortions

Crosstalk: failure in the separation of the two retinal images. The result is the so-called ghosting effect, i.e., the viewer sees the object as having blurred and overlapping edges.

Keystone distortion: the image is shrunk at the upper or lower edge, it increases with the increase of the convergence.

Cardboard effect: the objects are represented at different depth planes, but the appear as flat cardboard images.

Excessive negative parallax: when the object is too close to the viewer, it is almost impossible to focus on it.

Giantism and Lilliputism: the objects' dimension is unnaturally big or small and unrelated to their position in the space.

Multiple points of reference: the display of subtitles or labels in the foreground could bias the depth perception of the other objects in the scene

measure are well-known (e.g., it can be quantified on a ratio scale, it is independent of subjective biases, etc.). On the other hand, these methods are often invasive, expensive, and require the intervention of an expert clinician. This is not always possible and in any case these measures are not necessarily correlated with the subjective evaluation, which appears to be a crucial aspect that will make the individual repeat the experience of watching a 3D movie in the future 2, 3]. The subjective assessment of discomfort could encompass both physiological symptoms (like the feeling of eye strain, eye dryness, nausea, etc.) and psychological feelings (like dizziness, the difficulty in focusing on the desired objects in the scene, problems in sustaining attention, etc.) [2,10].

Objective factors inducing visual discomfort

According to the literature, the main objective factor that could produce visual discomfort in 3D technology is the accommodation-convergence conflict [2]. In natural viewing conditions, accommodation (the control of the depth of focus) and convergence (the control of eyes angles) are two intertwined processes that are always interacting via cross-links. Viewing a 3D display disrupts this interaction, because the accommodation should be stable and linked to the screen distance, while the convergence should vary according to the illusory position of objects in the space around the screen. This unnatural decoupling could elicit the feeling of discomfort. Other objective factors are: excessive screen disparity of the two instances of the image on the screen; perceptual inconsistencies (e.g. seeing an object as closer than the screen, but falling outside its frame); screen point of view and age-related eye physiology [10], technology-based stereoscopic distortions (see box aside).

Subjective factors inducing visual discomfort

Although objective factors can be addressed through the improvement of technology and devices, the subjective experience of viewers must still be taken into account, since it is the main determinant of their attitude towards the 3D technology. Several researchers previously attempted to measure visual discomfort but nobody, as far as we know, took into account both the psychological and physiological issues. For instance, the International Telecommunication Union (ITU) recommendations refer to the subjective assessment of visual discomfort [7, 11], but their scale is generically oriented to the evaluation of image quality and is mainly interested in comparing the subjective judgments of several kinds of images and displays. The Advanced Television System Committee (ATSC) developed a rating scale for visual discomfort, but it was based on a single item Likert scale ranging from "very comfortable" to "extremely uncomfortable" [12], which can be useful and efficient in some research contexts but cannot provide a comprehensive assessment of all the subjective factors leading to visual discomfort. Other scales take into account just the subjective rating of the physiological effects, listing symptoms related to eyes strain, clear vision, head ache, nausea, palpitation [13, 14]. For instance, Lambooij et al. [2] developed the Convergence Insufficiency Symptom Survey (CISS), which is based on the evaluation of physiological symptoms like feeling sleepy, seeing words jumping or moving, double vision. To our knowledge, Yang et al. [10]'s visual and physical discomfort questionnaire was among the few who included also psychological effects. They listed 15 items such as being tired, feeling dizzy, feeling disorientation and vertigo, seeing multiple images, difficulty in thinking and remembering. However some crucial

1. I had problems in sustaining my concentration during the movie
2. I felt physically uncomfortable
3. I felt neck pain
4. I had the feeling of vomiting
5. I felt that the picture was doubled
6. I felt my head was heavy
7. I felt sleepy
8. My vision was blurred
9. I felt I was in a haze
10. I felt demotivated to continue watching the film
11. I felt dizzy
12. I saw the words moving, jumping, floating on the screen
13. I felt my heart was beating stronger
14. I felt my back was tired
15. I felt mentally confused
16. I felt disoriented
17. I felt unable to control my vision
18. I felt a pulling sensation to my eyes
19. I felt more irritated
20. I had problems focusing my attention on the main elements of the scene
21. I had problems focusing my eyes on the scene
22. My eyes felt tired
23. I felt nauseous
24. I had problems remembering what I had seen

factors, such as disappointment, problems in focusing attention and directing the gaze among the elements in the scene are missing. In this study we thus aimed at developing a comprehensive measure of subjective visual discomfort that can overcome the shortcomings of the existing scales.

The Stereoscopic Discomfort Scale

We conducted a review of the literature with the aim of collecting all available measures related, even marginally, to the self-report of visual discomfort symptoms and feelings [7-9]. To obtain an adequate content coverage we also generated new items. For instance, one of the main problems of 3D movies is the depth of field and the blurring of background elements. This allows the viewers to feel engaged in the situation, but if they want to focus on other background elements, they are unnaturally blurred, since the focusing is decided by the director and forces the viewers to focus on the areas of interest. In addition, the physiological effects of visual discomfort could have psychological drawbacks like a decrease of motivation to watch the movie, or a general irritation due to the eye strain. To ensure consistency across answers, items were reworded to be rated on a 5-point, Likert-type agreement scale. The Stereoscopic Discomfort Scale (SDS) was thus comprised of 24 items (see box aside).

The experiment

The validation of Stereoscopic Discomfort Scale provides for the organization and staging of two different experiments. Within this document will be considered the first experiment planned, which involves the administration of Stereoscopic Discomfort in a battery of tests already validated. The procedure provides that subjects assist to a three-dimensional movie lasting at least 30 minutes. Following the vision of the movie we administered the Stereoscopic Discomfort Scale and we organized a debriefing with the participants in order to examine the clarity and completeness of the items of the scale.

Participants

Forty-nine participants (mean age 22.82±2.71 years, range 19-33, F=76%, 84% college students) volunteered to the experiment. All of them had normal or corrected-to-normal vision (glasses, contacts, etc.), provided their written informed consent to participate after having received a detailed description of the procedure and were not rewarded for their participation.

Materials and procedure

The entire experiment was conducted in the University Campus of Savona (Italy). Participants had first to fill in a battery of psychological scales including a measure of cognitive styles (Object-Spatial Imagery and Verbal Questionnaire, OSIVQ) [15], the Tellegen Absorption Scale (TAS) [17], the Vividness of Visual Imagery Questionnaire (VVIQ) [17]. Then participants saw a 40-minute movie (Dinosaurs: giants of Patagonia, 2007). We decided to use this video because it is characterized by an alternation of pleasant and disturbing framing. The film was presented on a 47-inch 3D TV which required the use of passive glasses with polarized lenses RealD. The administration took place small groups (10 people) to allow their optimal viewing of the content and avoid biases due to the excessive presence of other people. After the video, participants completed the SDS and the ICT-Sense of Presence Inventory (ITC-

Post-experiment debriefing

After the experiment participants were interviewed about the item's clarity and were asked to provide further discomfort issues not explicitly covered by the scale. The majority (77%) said that the items were easy to understand. Some (10%) considered the item 2's word "physically" too generic and could be due both to posture and vision. Another comment concerned item 10, where the demotivation could be due to the movie contents and not to the discomfort. Some participants (7%) argued that they would have preferred a rating based not on the agreement, but on symptoms' intensity. Items 18 and 22, and items 4 and 23 were considered very overlapping. Only 3% reported lacrimation. As further suggestions they advised to control: wearing normal vision glasses under the 3D ones (7%); environmental lighting (3%); asking for the same symptoms before the movie vision, as a baseline (7%). Among the main discomfort causes, they reported fast moving pictures and the perspective changes related to lateral head motion.

SOPI) [18]. All the procedure took about 1 hour to be completed.

Results

SDS items showed a high internal consistency, as indexed by the Cronbach's α (.95, *SE*=.01). Mean inter-item correlation was .43 (range –.05-.85), mean corrected item-total correlation was .66 (range .25-.79), mean squared multiple correlation was .86 (range .62-.95). A single factor explained 48% of total variance and the mean loading was .68 (range .27-.81). These results suggest that the SDS has adequate levels of internal reliability and unidimensionality. As shown in Table 1, SDS scores were only weakly and not significantly correlated with measures of cognitive style, absorption and vividness of mental images, whereas they were strongly associated with measures of presence.

Table 1 Pearson correlations of the Stereoscopic Discomfort Scale with the other measures employed in this study.

Scale	*r*
OSIVQ-Object	.25
OSIVQ-Spatial	.23
OSIVQ-Verbal	-.01
TAS	.12
VVIQ	-.06
ITC-SOPI - Ecological Validity-Naturalness	-.47**
ITC-SOPI - Engagement	-.67***
ITC-SOPI - Negative Effects	.88***
ITC-SOPI - Spatial Presence	-.59***

Note: **=p<.01, ***=p<.001

Correlations with ITC-SOPI scales of positive experience were negative, suggesting that a higher visual discomfort is related to worse subjective experiences, but all these correlations were significantly weaker than the positive correlation with the Negative Effects scale (z=4.05, p<.001).

Conclusions

The measure of subjective visual discomfort has assumed various definitions as reflected by the heterogeneous nature of its current self-report measures. We developed a scale, the Stereoscopic Discomfort Scale (SDS) that aimed at overcoming the shortcomings of these measures and providing a comprehensive assessment of all physiological and psychological effects that viewers of 3D displays can experience. In this pilot study we presented evidence of internal consistency, unidimensionality and construct validity of the new scale. However, the results should be considered as preliminary, since the relatively small sample size did not allow an accurate estimate of inter-item correlations and all the related statistics needed to investigate, e.g., item redundancy, which appears to be a major issue to be investigated in future studies, together with the consistency of SDS scores across different, more interactive, displays like portable displays, C.A.V.E.s, etc. The assessment of construct validity should also be replicated and extended: SDS scores were strongly correlated with facets of presence: higher levels of discomfort were associated with lower levels of perceived naturalness, engagement and spatial presence, and with higher levels negative effects. Taken together, these results let us argue that the SDS could be a valid tool for the subjective evaluation of users' experience of stereoscopic media.

Acknowledgements

We thank C. Grollero, S.Nutarelli, E. Bellanti, A. Corsi and S. Iacono for their help.

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