VISUAL STRESS SYMPTOMS FROM STEREOSCOPIC TELEVISION

Pancée Atallah[1], Adar Pelah[1] and Arnold Wilkins[2]

[1]Department of Electronics, University of York, UK
[2]Department of Psychology, University of Essex, UK
Correspondences to: <adar.pelah@york.ac.uk>

ABSTRACT

Visual stress from watching 3D TV and other stereoscopic displays has been reported by a number of studies. Alarming media reports of concerns for public health prompted the 3D industry to issue consumer guidance and warnings emphasising best practice and caution for susceptible groups. This study considers the importance of the problem by addressing the questions of prevalence, magnitude and significance of a range of symptoms and preferences associated with 3D viewing. A large cohort of 52 subjects (likely the largest used in such studies) with no pre-existing optometric or medical conditions viewed randomised 10 minute sessions in 3D or 2D. Results revealed a wide range of adverse symptoms of high magnitude and statistical significance for 3D, whether measured as a comparison between 3D and 2D or independently for each condition. In addition, an online survey of 106 participants concurred with subject preferences in indicating that 48% of respondents do not find 3D TV comfortable to watch. We conclude that visual stress and discomfort associated with 3D viewing is prevalent for a significant proportion of the healthy consumer population, and propose that the 3D industry address the problem on public health and commercial grounds.

Index Terms— 3D technology, 3D displays, 3DTV, visual stress, viewing discomfort, visual fatigue, 3D discomfort, stereoscopic displays.

1. INTRODUCTION

The use of 3D stereoscopic technology, and particularly 3D TV, is becoming increasingly widespread, with more people viewing 3D content in their homes and for longer periods of time[1] [2]. The term visual stress [3], often referred to as visual fatigue or visual discomfort, describes a range of symptoms associated with 3D viewing and can include headache, eye fatigue, nausea, blurred vision, dizziness and other symptoms. Studies reporting on the association between visual stress and 3D viewing have attributed its occurrence to a range of causes.

Generally in stereoscopic displays, the focal length remains fixed by the viewing distance to the plane of the display whilst convergence and divergence of the eyes is nevertheless required to align binocular content; the absence of the change in accommodation that would occur naturally for the depths represented in the image leads to the so-called vergence-accommodation conflict (e.g. Watt et al, 2005 [4]). Shibata et al [5] implicate principally the vergence-accommodation conflict for causing symptoms of visual fatigue and discomfort. Percival's 'zone of comfort' describes a sub-region (i.e. a set of vergence and focal distance stimulus points) in which an observer can retain binocular fusion without experiencing visual discomfort [6]. Using experimental conditions of either conflicting or non-conflicting depth cues, Shibata et al. [6] investigated, using 24 subjects, how the vergence–accommodation conflict associated with 3D technology has an impact on visual fatigue, finding an effect of viewing distance in relation to the zone of comfort, including an interaction between viewing distance and the sign of the vergence-accommodation conflict. The results of Emoto et al [7] also supported the hypothesis in their examination of the changes in fusional vergence limit in 12 subjects after 30 minutes of stereoscopic viewing.

In their review, Lambooij et al [8] concluded that the excessive demand of the vergence-accommodation linkage, as well as 3D artefacts arising from inconsistencies of spatial and temporal depth signals and unnatural amounts of blur, are mainly responsible for visual discomfort symptoms.

Other contributing causes to 3D visual stress have included cross-talk between the signals arriving at the two eyes [9], binocular colour or contrast differences, framing effects and unintended vertical parallax due to head-tilt. The level of comfort in 24 subjects was found to be adversely affected by imperfections in stereoscopic images by Kooi and Toet [10]. Although experiments on 47 subjects by Lambooij et al [11] suggested that stereoscopic displays have a greater impact on those individuals screened for moderate visual susceptibility (shown by an adverse effect on reading ability after 3D viewing), the effects were not limited to this group.

In the above studies therefore the underlying causes for visual stress from stereoscopic displays have been reported as attributable to deficiencies or imperfections in 3D technology. In contrast, the 3D industry has been equivocal in their public assessment of the causes and manifestations of visual stress from 3D viewing. Alarming media reports on health concerns associated with 3D viewing, prompted

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sections of the industry to issue official consumer warnings guarding against excessive exposure in particular for certain segments of the population. The largest manufacturer of 3D TVs, Samsung, initially warned consumers against a wide range of possible symptoms including confusion, nausea, convulsions, altered vision, light-headedness, dizziness, and involuntary movements, such as eye or muscle twitching, as well as cramps, and identified potentially vulnerable segments of the population as pregnant women, the elderly, children and sufferers of medical conditions such as epilepsy (e.g. Poulter [12]). Later warnings, however, have been more restrained, including advising against prolonged viewing periods, proposing periods of rest and advocating a cessation of viewing should visual discomfort occur [13].

The 3D industry consortium known as 3D at Home [14], which includes Samsung, Sony, LG and numerous other member companies and organisations, acknowledge the challenges inherent in the technology. 3D at Home Chairman Rick Dean implicitly stated [14] that in the future "…focus is going to be on the human factors, the comfort and the safety in the use of 3D". At the same time however, the consortium appears to defer public health matters associated with 3D viewing to the American Optometric Association (AOA), the professional body of US optometrists, with whom it signed a Memorandum of Understanding in 2011 [15]. For its part, the AOA provides consumer information on good practice in usage of 3D technology but also advises consultation with an optometrist to anyone experiencing visual problems from 3D viewing, indicating that such problems may be due to undetected visual conditions. On its website it encourages its members in an approach that "…captures both the public health benefits of 3D and capitalizes on the potential for new patients" [16].

Thus, while scientific studies continue to point to limitations in 3D technology as the primary reason for visual stress symptoms, there remains a question of whether for the majority of viewers visual problems are indeed due to the current state-of-the-art in 3D technology or are more likely to be indicative of a viewer's undetected medical conditions. A fuller understanding of the characteristics and prevalence within the general consumer population of symptoms of visual stress is therefore necessary. In this paper, we report experiments that quantify the level and range of visual stress symptoms from 2D or 3D viewing sessions as reported by 52 subjects, all of whom who self-report as having no underlying visual problems. Rather than investigating specific causes for visual stress by controlling the specific characteristics of 3D visual content (e.g. Lambooji [8]; Shibata [5, 6] etc.), the aim of this study is first to assess in a consistent viewing condition the collective effects, i.e. the range, magnitude and significance of the symptoms most likely to occur. We discuss from the results whether symptoms are of marginal prevalence statistically or whether instead they are likely reflect a wider prevalence within the TV viewing consumer population. Finally, in addition to cataloguing the symptomology we report on viewers' personal preferences for either 3D or 2D TV, as obtained both from the controlled viewing sessions and from a separate survey of 106 internet users.

We hope that the findings, based on what we believe to be the largest cohort of experimental subjects assessed for 3D vs. 2D viewing under controlled conditions to date, will support manufacturers of 3D TVs, 3D cinema and 3D content to rebalance priorities for achieving their goal of improving human factors and viewing experiences for a larger number of consumers.

2. EXPERIMENTAL DESIGN

The main objectives of the experiments are to identify, assess and quantify the significance of symptoms associated with viewing 3D in comparison to conventional 2D viewing. Recruited subjects participated in randomised viewing sessions with their responses obtained via questionnaire prior to the start of sessions and upon completion of each session. Data were then collected from participants regarding their viewing preferences, and a separate survey on 3D preferences and symptoms was conducted on the internet.

2.1 Subjects

Data were collected from 52 participants, 17 females and 35 males, between the ages of 18 and 56 years, all of whom work or study at the University of York. The experiments were approved by the Physical Sciences Ethics Committee at the University of York. Instructions were given to subjects in advance of the testing session and efforts were made to ensure that subjects were not aware of the purpose of the study. Subjects were all unpaid volunteers who signed an informed consent form indicating their awareness that tests may cause nausea, headaches or other symptoms. The experiments were judged unsuitable for individuals with photosensitive epilepsy [17] and therefore subjects explicitly confirmed that they did not suffer epilepsy and had no other conditions that might make it inappropriate for them to participate in the experiments. All subjects had normal or corrected-to-normal vision, and were determined to have adequate stereoscopic vision by assessing their ability to correctly identify a simple 3D random-dot shape through anaglyph filters. Importantly for this study, subjects therefore represented a mostly young cross-section of viewers who self-reported the absence of known pre-existing conditions or pre-dispositions to visual or related problems that would necessitate consultation with a medical professional.

2.2 Experimental setup, viewing conditions and visual stimuli

The experimental setup consisted of a comfortable chair for the subject to sit on while viewing a 24 inch diagonal 120

Hz display on a table positioned at a viewing distance of approximately 90cm from the subject, who wore active 120 Hz (60 Hz per eye) LCD-based 3D shutter glasses (not activated for 2D viewing) manufactured by NVIDIA (California, United States). Room illumination was dim (1.08 lux), and care was taken to eliminate glare and other artifacts from appearing on the display during the viewing sessions.

The results reported in this paper are based on two viewing conditions, labeled 2D (conventional display, shutter glasses worn but not activated), and 3D (stereoscopic display, activated shutter glasses worn). Results pertaining to a third condition and viewing session will be described elsewhere. Each viewing condition consisted of a 10 minute viewing session, with the order of presentations randomly assigned. The 3D (or 2D) stimulus shown in each session was an identical (either 3D or 2D) action sequence taken from the commercial film 'Resident Evil: Afterlife' played on a Blu-ray DVD player in HD and controlled by the experimenter.

2.3 Questionnaires

Questionnaires were used to assess the participants' visual comfort and experience while viewing stereoscopic displays, and were adapted from those used by Shibata et al [5] and by Hoffman et al [18]. Symptoms selected for analysis included eye strain, general discomfort, nausea, focusing difficulty and headaches, as measures associated with visual stress [19]. Three different written, multiple-choice questionnaires were completed by each subject, an Initial Questionnaire, a Symptom Checker Questionnaire and a Session Comparison Questionnaire, administered, respectively, prior to the start of viewing sessions, after each viewing session, and at the end of all viewing sessions.

2.4 Data analysis

Non-numerical data from the multiple-choice questionnaires were converted into an equivalent numerical scale. A score was determined by point allocation with the highest and lowest scores allocated to the best and worst response or condition respectively, and a similar scheme applied for preference ranking questions. The nominal ranking data are assumed to have non-normal distributions, so non-parametric statistics were chosen [20]. Non independence was assumed for tests between viewing conditions, as these might influence one another, while tests for viewing condition order were assumed to be independent. Significance tests used were the Mann Whitney U, for comparison of independent variables and nominal categories based on rankings, and the Wilcoxon Signed Rank for comparing related conditions before and after a viewing session. The Kruskal-Wallis test was used in cases where more than three categories of data were compared. Data were analysed using the statistical package SPSS.

The Initial Questionnaire was used as a baseline score, with each mean symptom score in the Symptom Checker Questionnaire compared to the mean initial value, in order to assess the impact on participants. Means were also assessed to identify whether the order of the viewing session had any influence on their responses.

The online survey, which is based on uncontrolled crowd-sourced results, are reported as proportions of the total responses (N=106) with no statistical tests applied.

3. RESULTS

3.1 Order effects

An independent samples Kruskal-Wallis test was conducted for each symptom and session comparison conditions and preferences, finding no statistically significant effect of viewing session order. With the exception of a weak viewing preference for 2D when viewed in the first viewing session ($p=0.054$), p-values for all symptoms and conditions were at $p=0.1$ and higher.

3.2 Session comparisons

The Session Comparison Questionnaire conducted at the end of all viewing sessions allowed participants to rank each viewing session based upon a set of specific criteria. The higher the mean the less severe the condition assessed, based on the ascending ranking scales used in the questionnaire. The difference between the means of 2D and 3D therefore represents the significance of the gap between the two viewing conditions. Results demonstrate statistically significant less severe conditions associated with the 2D viewings in comparison with 3D viewings. Thus, 3D viewings were associated with adverse effects shown in Fig. 1 as the percentage reductions in mean scores for 3D in comparison to 2D viewing sessions for the tested conditions.

The difference in 'Session preference' for 2D over 3D, obtained from the question "Which session was generally more comfortable?" without reference to displayed content shows a marginally significant ($p=0.085$) advantage, according to the Wilcoxon Signed Rank Test. On the other hand, 'General preference,' obtained from ranking the order of viewed sessions according to viewer experience while explicitly excluding video content, clearly favored 2D sessions ($p=0.001$). Conversely, an additional condition of 'Special effects' (not shown in Fig. 1; data bar would extend in opposite direction) demonstrated a strong preference in favour of 3D viewing sessions ($p<0.001$). A proposed explanation for these results is given in the Discussion.

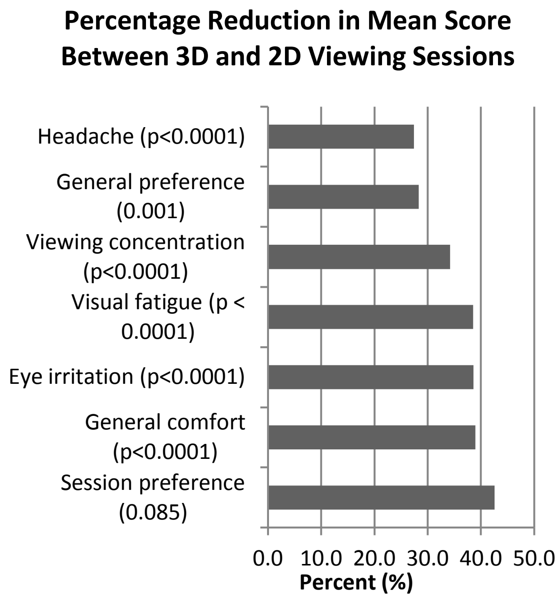

Fig. 1. The percentage reduction in rating scores from 2D to 3D viewing sessions from the Session Comparison Questionnaire. A small value indicates that 2D and 3D conditions have similar effects, while a large value indicates a greater percentage increase in adverse effect from 3D viewing. All values represent a significant increase of adverse response in the named condition for 3D viewing sessions. Values are based on rankings converted to a numerical scale. Associated p-values for the mean rankings of 2D and 3D viewings are shown in brackets or each condition.

3.3 Symptom checker

The Symptom Checker Questionnaire was completed subsequent to each viewing condition, and values were compared to baseline values obtained from the Initial Questionnaire conducted prior to all viewing sessions. As seen in Fig. 2a, where the frequencies of reported symptoms are expressed as percentages, 3D viewing increases the difficulty of focusing on displayed images, and in experiencing double vision and blurring, whereas dizziness, tearing or dryness and nausea are not experienced significantly differently between 3D and 2D.

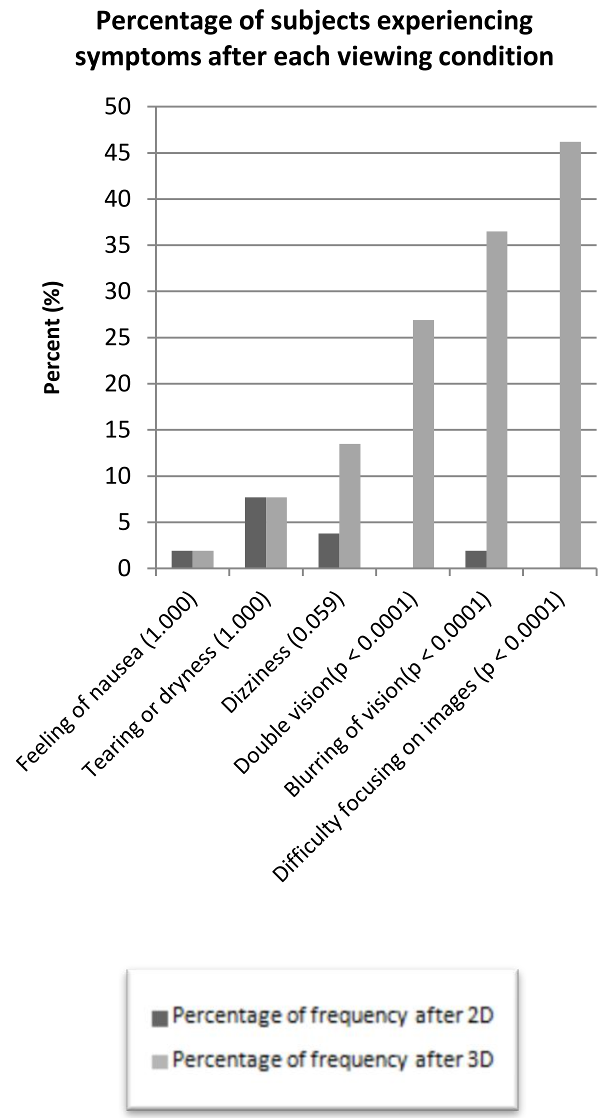

Fig. 2a. Percentage of subjects obtained from frequency or reports of experiencing symptoms after each viewing condition. Clear adverse symptoms are reported following 3D viewing sessions with respect to pre-session baselines for double vision, blurring and difficulty in maintaining focus, while no significant differences between post- and pre-session reports are seen between 3D and 2D for nausea, tearing or dryness no dizziness. The p-values for significance are shown for each symptom in brackets.

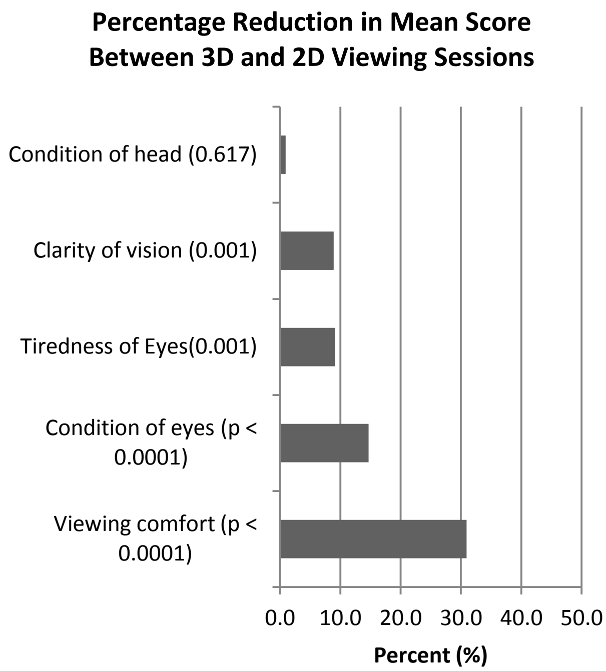

Fig. 2b. The percentage reduction in rating scores from 2D to 3D viewing sessions from the Symptom Checker Questionnaire. Responses are based on rankings converted into a numerical scale as in Fig. 1, except that viewing session mean scores were conducted after each viewing sessions and are referenced to pre-session baselines. Viewing comfort shows a strong and highly significant reduced effect for 2D viewing, with clarity of vision, tiredness and condition of the eyes also highly significantly reduced. Condition of the head is not affected by 3D in comparison to 2D viewings. Associated p-values for the mean rankings of 2D and 3D viewings are shown in brackets for each condition.

Fig. 2b is based on percentage reductions in symptom ratings, the same metric used in the Session Comparison Questionnaire (see Fig. 1). It demonstrates that viewing comfort is a highly significantly affected symptom in 3D viewings in comparison to 2D viewing, as are clarity of vision, and tiredness and condition of the eyes, while the condition of the head is not affected.

3.4 Online survey

An online survey was circulated via Google Forms containing questions on viewers' opinions and experiences with 3D TVs. 106 respondents, ranging in age between 18 and 60 (80 were aged 18-24; 20 were aged 25-44; 6 were aged 45-60), 57 males (49 females) and residing in 11 different countries, completed the survey. Viewers were not asked to view 3D content prior to completing the survey. Although it cannot be confirmed, their responses can be taken as based on their recollection and general impression of viewing 3D TVs from previous experiences (if any). As can be seen in Fig. 3a, respondents reported experiencing a range of symptoms of those included in the survey, with frequencies ranging from 12% to 44% of participants. The symptoms confirmed by the greatest percentages of participants were headache and blurred vision, with a catch-all 'other' category (implied in the context as adverse) also scoring strongly. In the opinion questions, 48% of respondents answered in the negative to the question of whether they found 3D TV comfortable to watch (see Fig. 3b), while 64% of responded affirming that they would view 3D TV more frequently if it were more comfortable to watch.

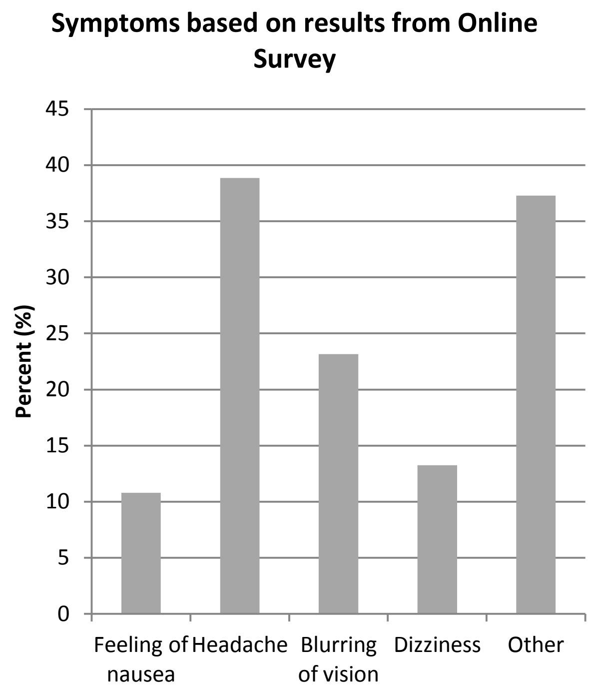

Fig. 3a. The figure shows percentages of respondents who reported the listed symptoms in relation to 3D viewing. Responses are from 106 participants, less those from the 12.3% who reported not to have previously watched 3D TV. Respondents ticked yes/no to questions on experiencing symptoms (a) and to their opinions (b) related to viewing 3D TVs. Nearly 45% of the respondents report experiencing headache, with blurred vision, dizziness and nausea also featuring strongly, and approximately 43% subscribing to a more widely or less defined (i.e. "other") adverse category of symptoms.

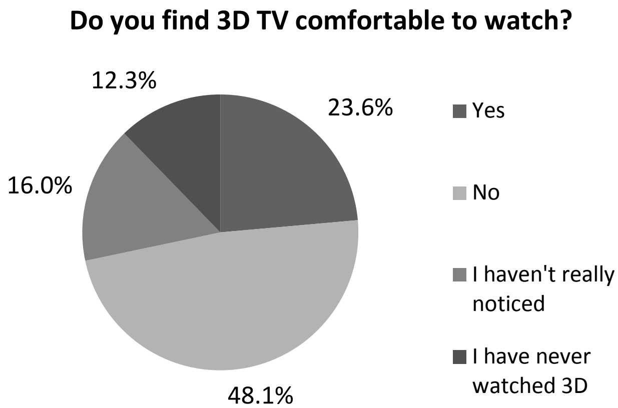

Fig. 3b. The percentages of respondents who find 3D TV comfortable to watch. Data is obtained from the responses of 106 participants in the online survey. Results are strongly indicative of a perceived discomfort and possible dissatisfaction with 3D TVs.

4. DISCUSSION

Previous research has investigated the causes underlying the visual stress experienced by viewers of stereoscopic displays, prominently implicating the vergence-accommodation conflict [4-7] and other causes (see [8]). By contrast, the present study consolidates previous approaches and findings, using an online cohort and the largest laboratory cohort to date, to assess viewer preferences and symptoms in comparative 2D and direct 3D viewing for the different purpose of concluding on the significance of the problem to industry and public health. Preferences and symptom categories both point to a highly significant negative impact of visual stress in viewer experiences with 3D technology.

The online market questionnaire of 106 internet users concerning their attitudes and experiences, suggests a large perceived problem with viewing comfort in 3D TVs. 48% of respondents indicated that 3D TVs were not comfortable to watch, with 'headache' being the largest single complaint. The large percentage, and the comparatively young age (76% were aged 18-24) of the majority of respondents, makes it unlikely that the problem can be attributed to pre-existing conditions.

The results from the laboratory-based controlled viewing sessions of 52 subjects provide similarly conclusive findings. Highly significant effects were reported by subjects when describing symptoms experienced in 3D and 2D sessions after all viewing sessions were completed (see Fig. 1). In particular, highly significant reductions in percentage mean score differences from 2D to 3D for named symptoms ranged from 28% to 39%, with "General Comfort" showing the greatest difference. However, when subjects were required to rank viewing sessions after all viewing sessions were concluded, there was a strong effect in favour of 2D when video content was excluded, whereas a marginal effect below significance is seen when it was not. This can be explained on one side by a 'pull' towards 2D of the strongly expressed adverse symptoms, while on the other side by the 'push' in favour of 3D for its significant advantage in the category of "Special effects" (see Section 3.2). 3D technology manufacturers and creators of 3D content may take this as a positive prospect ultimately for potential viewer affinity for 3D TVs, provided the highly significant and prevalent adverse symptomology can be removed or reduced significantly.

Conclusions from the independent comparisons made by subjects from 3D and 2D viewing sessions to a pre-session baseline are similarly instructive. The prevalence of reported symptoms in the sample is very high for 3D, 26% reporting double vision, 37% reporting blurring of vision and 46% reporting difficulty in focusing, compared with negligible values in the 2D case (see Fig. 2a). However, there were low and non-significant differences in percentages of subjects who reported tearing or dryness, nausea or dizziness, the latter two symptoms having previously appeared in issued warnings [12]. Viewing comfort and both specific and general symptoms of the eye that were observed in the conclusions of all viewing sessions are similarly confirmed in these independent post-session baseline comparisons (see Fig. 2b), supporting the conclusion that visual stress from 3D is highly prevalent and significant on its own whether or not 2D is available to view for comparison.

5. CONCLUSIONS

The study has shown that adverse symptoms from 3D viewing are significant, range widely, common and of high subjective magnitude, as assessed both independently for 3D alone and in comparison with 2D viewing. The range of significant symptoms is wide, including most of those raised in the questionnaires, several of which (e.g. headache, general comfort) are unlikely otherwise to be prevalent in the relatively young cohort of subjects who attest to no pre-existing medical or optometric conditions. Preferences in terms of symptomology significantly favour 2D viewing, while the special effects that are available from 3D are also valued. Significant problems persist with 3D TVs and related technologies in terms of consumer experiences and attitudes. The 3D industry may consider the findings in the context of public health and commercial interests by rebalancing resources used in the promotion of 3D TVs in favour of improving 3D viewing comfort.

6. ACKNOWLEDGEMENTS

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