SIMULATOR SICKNESS – FIVE EXPERIMENTS USING AUTOSTEREOSCOPIC MID-SIZED OR SMALL MOBILE SCREENS

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ABSTRACT

Visual comfort is one of the factors of 3D experience. The goal of this paper is to evaluate simulator sickness as a part of five different video quality evaluation studies. The experiments are conducted using three different dual-view autostereoscopic mid-sized and small mobile screens with varying constructed video quality levels, under different lengths of viewing, and with a total of 200 participants. The simulator sickness questionnaire (SSQ) was used in the data-collection in the pre- and post-immersion. The results showed only a small short term increase in the symptoms after exposure in four studies indicating a good applicability of these displays for short term video viewing.

Index Terms — Simulator sickness, autostereoscopic dislays, dual-view, video quality, visual comfort

1. INTRODUCTION

The advent of three-dimensional autostereoscopic displays has brought forth the need to measure visual comfort and eye-related symptoms. This is due to the notion that quality of experience is built upon produced technical quality and viewers' perceived quality. Perceived quality can be lowered by visual impairments, eye-related symptoms and general discomfort. These negative factors can destroy the added values of three-dimensionality: perceived depth and the feeling of being there [2]. To be successful, the new technology must provide at least comparable level of experience when compared to existing technology [6]. However, even if the impairment is slightly annoying and perceptible, viewers may still prefer stereoscopic content if the added value is considered large enough to compensate for the experienced annoyance [2].

Previous research with autostereoscopic displays suggests that visual discomfort and visual fatigue are common byproducts of three-dimensionality [6]. In autostereoscopic displays, visual discomfort is often caused by impairments in stereoscopy, such as keystone distortion and crosstalk [2], [7]. The experienced visual discomfort may also degrade the perceived image quality and cause annoyance [6] lowering viewer satisfaction and acceptance of the novel technology. Three main approaches to studying visual discomfort can be identified: 1) explorative studies, 2) psychophysical scaling and 3) questionnaires [6]. Questionnaires are commonly applied to subjectively study the degree of visual discomfort.

Kennedy et al. (1993) [1] originally developed the Simulator Sickness Questionnaire (SSQ) to study sickness related symptoms induced by aviation simulator displays. The questionnaire combines individual symptom measures to produce combination measures of nausea, oculomotor symptoms, disorientation and a combined total severity score to subjectively quantify the experienced symptoms of the participant. Since its conception, SSQ has also been applied to several fields outside the aviation research community. Jaeger & Mourant (2001) [4] compared simulator sickness symptoms with static and dynamic virtual environments. They concluded that increased duration of exposure intensifies sickness symptomology. During their longest session of 23 minutes, they did not observe physiological adaptation that would lessen the symptoms during prolonged exposure. Häkkinen et al. (2002) [3] applied SSQ to study stability and sickness symptoms after Head-Mounted Display (HMD) use. They noted that stereoscopic game playing induced strong nausea and disorientation symptoms with the worst symptoms being experienced within 10 minutes after task completion. However, the symptoms diminished with time. Oculomotor symptoms were experienced independently of the used stimuli; however symptoms induced with game playing lasted longer. The authors conclude that additional visual strain must have been caused by movement and stereoscopic stimuli. In a similar study, Pölönen & Häkkinen (2009) [5] measured sickness symptoms using SSQ with three different applications while using a Near-to-Eye Display (NED): movie viewing, game playing and reading. Their results show that discomfort was experienced with all applications, especially with reading using the NED. Almost half of the participants experienced nausea and eye strain during reading. Disorientation was experienced especially when playing games with strong motion scenes. Movie viewing invoked the least symptoms of the three applications. Lambooij et al. [7] note in their review of stereoscopic displays and visual comfort that induced blur may cause unnatural depth perceptions. They also emphasize that spatial and temporal inconsistencies and conflicting depth cues are a cause for annoyance and visual discomfort.

To sum up, these previous studies have examined the visual discomfort and simulator sickness under displays, tasks and qualities for 3D presentation while the studies for examining these phenomena for small mobile or mid-sized screens are limited. In this paper, we present the results of five different experiments using devices equipped with autostereoscopic displays to watch synthetic or natural video contents. The experiments were conducted using three different portable devices with relatively small autostereosopic displays. In each experiment, SSQ measurement was used.

2. RESEARCH METHOD

Simulator Sickness Questionnaire - This study contains five different experiments. The Simulator Sickness Questionnaire (SSQ) was applied [1]. It contains 16 physical symptoms rated on a categorical labeled scale (none, slight, moderate, severe). The symptoms are contributing to groups of 1) nausea (e.g. stomach awareness), 2) oculomotor (e.g. eyestrain), and 3) disorientation (e.g. dizziness). The SSQ was collected prior to immersion and several times after immersion (after 0, 4, 8, 12

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minutes) in the experiments 1-4. In the experiment 5, only immediate post-immersion was collected after two immersive sessions. In the analysis, the total SSQ scores of the four groups are calculated by summing the ratings of related symptoms in each group [1]. Each sum is then multiplied by a weighting score which has been defined by varimax factor weights during SSQ development [1]. The weight scores are: Nausea = 9.54, Oculomotor = 7.58, Disorientation = 13.92 and total score = 3.74. In this paper, the absolute values are presented.

Procedure - The structure of all experiments was similar. Pre-immersive evaluation of SSQ was collected at the beginning. For the immersion, psychoperceptual quality evaluation task was used. It contained both viewing and rating stimuli independently [18]. During the rating participants gazed off screen, partly resembling typical mobile video viewing situation [15]. SSQ was applied after completing immersive psychoperceptual evaluation task (one or several times). After, completing SSQ, the descriptive quality evaluation task was conducted in the experiments 2-3, and 5.

Characteristics of the experiments - The characteristics of experiments are in Table 1. Experiment 1 targeted the evaluation of a suitable surround sound setup for a 15" autostereoscopic laptop [11]. Experiment 2 aimed on identifying audiovisual experienced quality under monoscopic and stereoscopic video presentation [12]. Experiment 3 [13] explored the influence of video coding methods and experiment 4 [14] transmission parameters on experienced quality of mobile 3D television. Finally, experiment 5 studied different video coding parameters. The experiments 1-4 were conducted in the controlled viewing circumstances [17]. The experiment 5 was conducted in both controlled and in-door quasi-experimental settings [15].

Heterogeneous stimuli material was used in the experiments. The stimuli contained synthetic and natural video scenes, variable depth levels, motion and impairments. Based on the descriptive quality evaluation tasks, the experiments 2 and 5 contained detectable impairments in spatial and depth domains while experiment 3 resulted in only spatial impairments. Finally, rated overall quality in the psychoperceptual studies was highly acceptable except in experiment 5.

Apparatus, displays - Three dual-view autostereoscopic displays were used in the experiments. Such displays work by showing a different image to each eye of the observer. Dual-view displays generate two images which are spatially interleaved – half of the sub-pixels are visible from one direction and the other half from another direction. The light of the display is redistributed by an optical filter – either parallax barrier (Figure 1a), which selectively blocks the light or lenticular sheet (Figure 1b), which refracts the light in different directions [8]. When the display is correctly positioned in respect to the observer eyes, as marked with "1" and "2" in Figure 2, it is possible to perceive 3D objects as freely floating in front of the display. In some autostereoscopic displays the optical layer can be turned off, which allows the display to be used for 2D images. In other displays, where the optical layer is static, the only option is to duplicate the visual information, and make the same image visible by each eye of the observer.

The first display used in the experiments is Actius AL-3DU by Sharp, which uses switchable parallax barrier [8]. Every other sub-pixel of that display belongs to the alternative view. As each view is visible from multiple angles, and the angle of visibility of one view is quite narrow, it is possible for an observer to perceive reversed stereo image, as is for observer at position 3 in Figure 1c. The visual quality of the 3D scene is very sensitive to the observation angle - except for three narrow observation spots the display exhibits noticeable moiré and ghosting artefacts. In 3D mode, the resolution per view is 512x768px at 42.5 DPI, with pixel aspect ratio of 2:1. The viewing distance in the experiments was ~55 cm.

The second display is 3D display by NEC with horizontally double-density pixel arrangement, also known as HDDP display [10]. Due to special pixel arrangement it has the same resolution in 2D and 3D mode, namely 427x240px at 155DPI. Its optical layer is lens-based and cannot be turned off, and 2D display mode is achieved through pixel doubling. The HDDP display is with the lowest crosstalk and the highest visual quality of the three. The 3D effect can be observed from a wide range of angles and distances. The viewing distance in the experiments was ~45 cm.

The third display that was used is Stereoscopic 3D LCD MB403M0117135, produced by masterImage [9]. It uses Cell Matrix Type parallax barrier which can be switched between portrait 3D and landscape 3D mode. The display is 2D/3D switchable with 2D resolution of the display is 800x480px at 200 DPI and the 3D resolution is 400x480px at 100 DPI. The views of that display alternate for each 3 sub-pixels – every second full pixel belongs to alternative view. This creates specific color tint artefacts in 3D mode, caused by sub-pixels with certain color being partially covered by the barrier. As the 100DPI resolution was deemed high enough, 2D images were shown using 3D mode and pixel doubling. The viewing distance in the experiments was ~40 cm.

3. RESULTS

The analysis targeted three main aspects: To explore 1) the influence of immersion by comparing pre- and post-immersive evaluations, 2) influence of post-immersive time on evaluations, and 3) to identify the time when post-immersive symptoms are reduced back to the pre-immersive level. As an overall tendency, the immersive period caused a short term peak to the total simulator sickness and its factors.

1. Pre vs. post immersion - The immersion significantly increased the symptoms. Wilcoxon pairwise comparisons showed a significant difference between pre and post evaluations in 14 out of 15 cases ($p<.01$, cf. Figure 2). There are two exceptions to this main result. In the first experiment, the immersion did not influence the severity of nausea symptoms ($Z =-1.46$, $p=1.43$, ns). In the second experiment, a lower level of nausea was reported after the immersion being in the contradiction to the main tendency of results ($Z =-2.30$, $p<.05$)

2. Influence of post-immersive time - After the immersion, both individual and total symptoms reduced over time (cf. Figure 2). Time (cf. Table 1) has significant influence of the symptoms in the experiments 1-4. As an exception, this influence was not announced in the case of nausea of the first experiment.

3. Reduction of post-immersive symptoms - Immersion caused a short term peak to simulator sickness score or its factors and starting level of pre-immersive scores was mainly reached within eight minutes after immersion. The level of pre-immersive total and oculomotor scores was reached in four minutes after immersion in three experiments (1, 2, 3) while it was not reached within the twelve minutes in experiment 4 ($p>.05$). In the terms of disorientation, to recover from immersion required from four to twelve minutes (Exp 1: 8min, Exp 2-3: 4min, Exp 4: 12 min, $p>.05$).

Table 1. Characteristics of the experiments

EXPERIMENT [Reference]	IMMERSION Length of viewing Total length	DISPLAY	CONTENT CHARACTERISTICS	SAMPLE N	EFFECT OF TIME (post-immersion)
EXP 1 [11]	Viewing: 4min Total: 6.7min	Actius AL-3DU 512x768px at 42.5 DPI 15''	Length: 15sec Videos: Synthetic Motion: Moderate 3D: 100% of time Described impairments: N/A Quality level: Highly acceptable	32	Nausea: F_R=6.42, df=3,p=.93, ns Oculomotor: F_R=10.95, df=3, p<.05 Disorientation: F_R=17.73, df=3, p<.001 Total: F_R=27.52, df=3, p<.001
EXP 2 [12]	Viewing: 13.9min Total: 23 min	HDDP 427x240px at 155DPI 3.5''	Length: ~ 18s Videos: Synthetic and Natural Motion: Variable 3D: 50% of time, 2D:50% of time Described impairments: Depth , spatial Quality level: Highly acceptable	42	Nausea: F_R=14.89, df=3, p<.01 Oculomotor: F_R=31.04, df=3, p<.001 Disorientation: F_R=39.89, df=3, p<.001 Total: F_R=51.17, df=3, p<.001
EXP 3 [13]	Viewing: 7.9min Total: 15.8min	HDDP 427x240px at 155DPI 3.5''	Length: ~ 10s Videos: Synthetic and natural Motion: Variable 3D: 100% of time Described impairments: Spatial Quality level: Highly acceptable	38	Nausea: F_R=30.29, df=3, p<.001 Oculomotor: F_R=29.52, df=3, p<.001 Disorientation: F_R=48.41, df=3, p<.001 Total: F_R=61.92, df=3, p<.001
EXP 4 [14]	Viewing: 32 min Total: 37.3 min	HDDP 427x240px at 155DPI 3.5''	Length: ~ 60s Videos: Synthetic and natural Motion: Variable 3D: 100 % of time Described impairments: N/A Quality level: Highly acceptable	77	Nausea: F_R=13.5, df=3, p<.01 Oculomotor: F_R=48.55, df=3, p<.001 Disorientation: F_R=27.49, df=3, p<.001 Total: F_R=53.14, df=3, p<.001
EXP 5 [15]	Viewing: 46min [23 + 23] Total: 54.8min [27.4 + 27.4]	3D LCD 400x480px at 100 DPI 3.3''	Length: ~ 30s Videos: Synthetic and natural Motion: Variable 3D: 80% of time, 2D: 20% of time Described impairments: Depth , spatial Quality level: Mainly unacceptable	30	

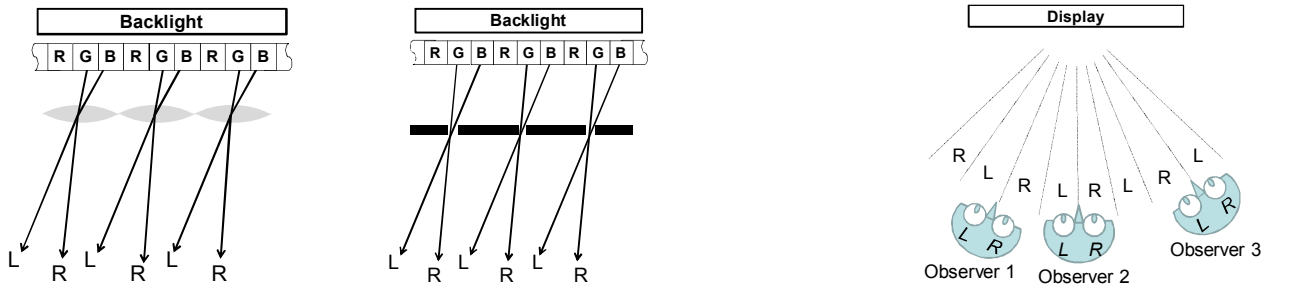

Figure 1. Redirecting the light of an autostereoscopic display: a) lenticular sheet, b) parallax barrier, c) Observation

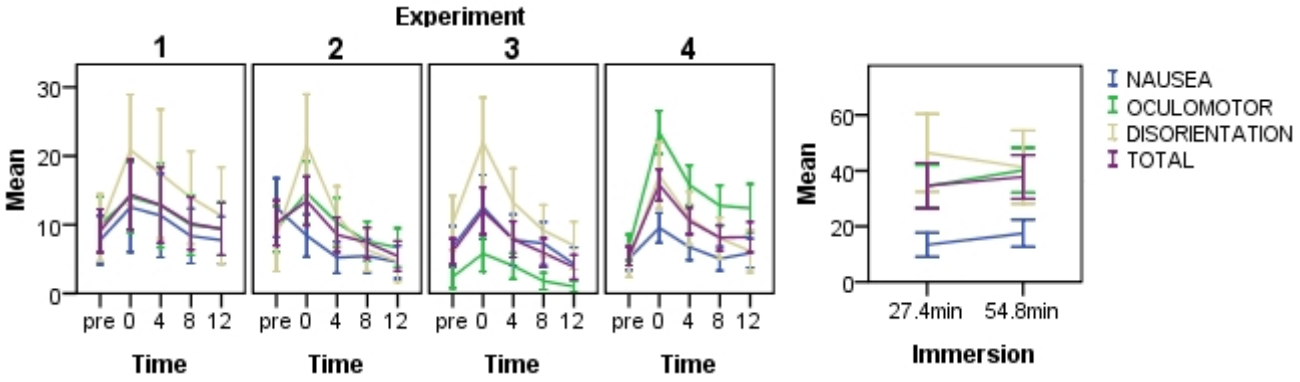

Figure 2. The results of total simulator sickness symptoms and its factors in the experiments 1-4. The experiment 5 shows the post-immersive measures after two exposures. Pre = pre-immersive measure; time 0-12 = the post-immersive measurement time in minutes. The bars show 95% CI of mean.

Finally, the pre-immersive level of nausea was equal after immersion (Exp 1; $p>.05$), it become lower after immersion (Exp2; $p<.05$), or it was reached within four minutes (Exp 3-4; $p>.05$). In total, the results showed that the recovering time was prolonged after a long immersive period of viewing 3D in the experiment 4 compared to the other experiments. This result is especially visible in oculomotor factors, as well as in total simulator sickness and disorientation.

In experiment 5, the post immersive evaluations were collected two times, immediately after viewing at 24.7 min and at 58.4 min (Figure 2). There were neither differences in the total simulator sickness (Wilcoxon: $Z=-1.301$, $p=.193$) nor in its factors (nausea: $Z=-1.789$, $p=.074$, oculomotor: $Z=-1.85$, $p=.064$, disorientation: $Z=-.794$, $p=.43$) between the post immersive measurements. Overall, the experiment 5 showed a higher level of symptoms in all evaluations compared to the other experiments.

4. DISCUSSION AND CONCLUSIONS

The goal of this study was to explore the simulator sickness symptom severity in five quality evaluation experiments conducted on three mid-sized or small mobile autostereoscopic displays. Our five experiments were characterized with variable length and structure of video viewing, overall quality of stimuli and nature of perceivable impairments. Although the variable characteristics of the settings can limit the direct between experiment comparisons, our results are beneficial for showing the general tendency of visual comfort in these experiments.

The results showed a slight and mainly short term increase in the symptoms after immersion. In these studies, the overall quality level was acceptable for the prospective consumer [14]. Firstly, the reported level of symptoms in our studies with HDDP and Actius ALDU displays are equal or lower compared to previous studies using CRT or Head-Mounted Displays after 40 min lasting fast-speed gaming [3]. Secondly, the pre-immersive level of simulator sickness symptoms was reached mainly within the first four minutes when active viewing time was less than 14 minutes. For longer viewing time (more than 30 min) on a small sized HDDP display, the recovery time was slightly prolonged. These results indicate that short term video viewing (e.g. typical for mobile television and video), on these autostereoscopic dual-view displays is not offending.

The results also showed a relatively high level of symptoms after a long viewing task on a 3D LCD display. In this study, the overall quality level was low for users and some of the used stimuli were highly impaired, causing perceptual problems such as cross-talk. In this study, the viewing time (23 or 46 min) did not increase the symptoms. This might be explained by physiological adaptation. According to Stanney et al. [16], under prolonged exposure, near or over 30 min can even lessen the symptoms due to the physiological adaptation.

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