Evaluation of Visual Discomfort Factors in the Context of HMD Usage

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Abstract

The growing number of head mounted displays (HMDs) used by users without previous knowledge in using HMDs leads to situations where the HMD user experiences unintended visual stress. This may be due to wrong adjustments of the visual system, such as dirty or scratched lenses; mistakes in the design of the VR experience like flickering images; and asymmetric presentation of pictures for the left and the right eye. It is difficult for VR developers to detect visual stress faced by a HMD user as the developer is not present when it occurs and the user does not report it. Therefore we propose to explore systems that use electroencephalography and eye tracking that automatically track the users state in order to detect visual stress. We conducted an online survey with an initial number of five VR developers. Normally this does not yield significant findings, and more participants for further research are expected. Nevertheless, first study tendencies reveal that the eye straining factors, such as 'position tracking error' and 'jitter', 'flicker', and 'blurred vision' have high occurrences in developers everyday practice. Further, initial results indicate a lack of awareness of VR and HMD developers about eye strain factors, including significant ones like the *vergence-accommodation conflict.*

Index Terms: Head-mounted display—Asthenopia—Eye Strain—Measurement Methods—Brain activity—EEG;

1 Introduction

The commercial distribution of cheap head mounted displays (HMDs), like the Oculus Rift [1] has a high potential to change our entertainment and working behavior due to its highly immersive characteristics. In order for the HMD to be a success, it is necessary for the consumer to experience it without any disturbance.

However, HMDs are complex visual systems that can be a threat for the users' eyes and their cognitive system [15]. Users may experience asthenopia, also known as eye strain, after using a HMD. [8] [19]. There are a lot of causes of asthenopia in conjunction with HMD usage, such as bad design of lenses, mistakes in the software, or misuse. The emergence of asthenopia and its causes are difficult for developers and system operators to detect. This is because it is problematic to assess a users experience of the HMD due to the devices nature. Once worn, no one else can look into the HMD and experience it in real time, except the user itself. While the operator can monitor the images on a screen, it does not show the same stereoscopic picture as in the HMD. Further, the user also may not report his or her experience to the operator. Although our work focuses mainly on detecting visual stress caused by HMDs, there are overlapping challenges for augmented reality (AR) or video see-through systems. This is due to the similarity in the hard and software technology. Both AR and VR headsets have a computer that renders a mono or stereoscopic picture that is displayed on a screen in the headset and distorted by an optical system. Therefore visual stress might be produced in a number of similar ways. For example flickering of the presented picture might occur in either AR, video see-through headsets, or HMDs. The *accomodation-vergence conflict* can also produce stress in both cases, as they both present a stereoscopic picture to the user. We will mainly focus on the usage of HMDs, but the results might be transferable to AR headsets.

Figure 1: User wearing a HMD to monitor the visual stress.

We look into methods to detect visual stress objectively on an individual level. We propose to use electroencephalography as it is shown to be able to detect visual stress in a HMD caused by visual disparity [13] in combination with eye tracking (Figure 1).

In order to examine the most relevant causes for visual stress, we conducted an online survey where we asked five developers for the main perceptual issues they encounter in everyday work. We also let them rate these perceptual issues in HMDs in order to get an insight on the awareness of visual threats.

2 Related Work

Asthenopia is a broadly defined subjective visual disturbance that is nearly synonymous with eye strain. The term includes non-specific symptoms such as eye fatigue, discomfort, burning, irritation, pain, sore eyes, and headaches, as well as specific symptoms such as blurriness, double vision, itching, tearing and dryness. [17] A lot of research about asthenopia in the field of stereoscopic images has been conducted, but little work focusing on state-of-the-art HMDs has been done.

2.1 Asthenopia in HMDs

Asthenopia caused by HMD usage results from VR experiences comprising problematic visual content or non-optimal HMD conditions. Regarding visual content, research has shown that stereoscopic images are the major causes of visual discomfort. Lambooij et al. [10] refers to four categories of related issues: anomalies of binocular vision; dichoptic errors, such as geometrical distortions and binocular asymmetries [9] [1], vergence-accommodation mismatches [3] [6] [18] and excessive binocular parallax [20]. Modern systems like the *Oculus Rift* in combination with state of the art engines and renderers, e.g. Unity, take into account a lot of these factors. One such example is the separation and synchronisation of the left and right eye images. This will prevent the emergence of asthenopia and further issues emerging from HMD usage such as described by Patterson et al. [15]. But these systems cannot prevent all causes and can be overruled by the developer, e.g. strong stereoscopic disparity when getting close to an object [13] or stress due to

[1] https://www.oculus.com/rift

long term use which may cause eye strain because of stereoscopic content [11]. Regarding HMD condition, problems like blurred vision or binocular asymmetries e.g. due to low resolution or dirty lenses may arise. In order to avoid those issues, appropriate measurement methods for detecting visual discomfort are necessary.

2.2 Methods of Measuring Asthenopia and its Causes

For measuring visual stress subjective and objective measurement methods can be applied.

Subjective methods
Explorative studies, psychophysical scaling and mostly questionnaires are largely accepted and used in assessing visual discomfort. For evaluating visual fatigue single stimulus continuous quality evaluation (SSCQE) [20], the simulator sickness questionnaire (SSQ) [13] and various experiment-specific questionnaires [3] [12] have been used. They are suitable to gain an understanding on factors that cause visual discomfort, degree of severity, and occurrence frequency. Regarding applicability during the VR experience, subjective methods have the drawback of requiring the users entire attention and therefore not providing data for real time assessment.

Objective methods
According to Lambooij et al. objective assessment of visual discomfort and visual fatigue can be achieved by three methods:

Optometric instrument based measurements
These measurements rely on devices determining how strong an indicator for visual fatigue changes after exposure to the stimulus causing visual stress. These measurements are useful to gain an overall understanding about causes of visual discomfort. [3] [20] However, these measurements are costly and time-consuming. Drawing reliable conclusions is difficult due to its impracticability during stimulus exposure. [10]

Optometric clinically based measurement
Clinically based methods in contrast are cheap and suitable for a large group of participants. However, the number of useful clinical tests is small, due to the rapid reduction of perceived visual fatigue after being exposed to the stimulus causing visual stress. [10] In an experiment, users stated they felt discomfort after wearing a HMD, while objective clinically and instrument-based measurements did not yield results showing harm done to the user [16].

Brain activity measurement
The third measurement method is based on recording brain activity to gain insight into the visual discomfort experienced by the user. Several techniques such as *functional magnetic resonance imaging* (fMRI) [7], *magneto encephalography* (MEG) [5], *functional near-infrared spectroscopy* (fNIRS) [2] and *Electroencephalography* (EEG) have been applied. While fMRI and MEG require large devices, approaches recording brain activity of users consuming stereoscopic images via EEG correlated with subjective measures show feasible results. [12] [14] [4] [13] Applicability of EEG in real time and availability of consumer-friendly EEG devices make this approach promising for future visual discomfort detection.

The present examination shows that a lot of research has been made concerning asthenopia in conjunction with stereoscopic images and its measurement methods, but little concentration on measuring issues users may face engaging with HMD. To our knowledge, there is no further work existing that examines this area of research incorporating the estimation of practitioners by conducting a survey described in the following.

	Severity to eye strain					Occurrence frequency				
	0	1	2	3	n/a	0	1	2	3	n/a
Display and Technology Issues										
Position Tracking Error and Jitter			2	2	1			3	1	1
Lag	2	1	1	1		1	2	2		
Flicker			1	3	1			2	2	1
Blurred Vision		3	2					1	4	
Excessive Binocular Disparity										
Horizontal Disparity			3	2		1		2	2	
Vertical Disparity				4	1	2	2		1	
Binocular Asymmetries										
Stronger blur on one eye		1	2	2		1	2		2	
Binocular Rivalry			2	3		2	2		1	
Differences in Contrast and/or Luminance	1	1	1	2			3	1		1
Color Asymmetry			2	2	1		3	1		1
Binocular Asymmetries in general			2	3			2	2	1	
Vergence-accommodation conflict			4	1			1		4	
Eye Strain in VR development										
Severity of impact of eye strain to the user experience in general		1	3	1						
Occurrence frequency of eye strain factors in your development							2	2	1	

Figure 2: Study results
Scaling for 'Severity to eye strain':
0: negligible, 1: marginal, 2: significant, 3: critical;
Scaling for 'Occurrence frequency':
0: incredible, 1: improbable, 2: remote, 3: frequent

3 Online Survey on Eye Strain Factors

3.1 Method

We constructed an online survey in order to examine (1) the general emergence of visual stress, and (2) the developers perceptions of the load created for the user by visual stress. We further separated the questions according to the presented related work on asthenopia. The categories in the survey were clustered according to 'Long-Time Use', 'Display and Technology Issues' ('Position Tracking Error and Jitter', 'Lag', 'Flicker'), 'Blurred Vision', 'Excessive Binocular Parallax / Disparity' ('Horizontal Disparity', 'Vertical Disparity'), 'Binocular Asymmetries' ('Stronger blur on one eye', 'Binocular Rivalry', 'Photometric Asymmetries', 'Crosstalk', 'Differences in Contrast and/or Luminance', 'Color Asymmetry', 'Spatial Distortions'), 'Vergence-accommodation conflict' and 'Eye Strain in VR development in general'. The participants were able to comment on each question and on the questionnaire in general.

All questioned answered using a four step *Likert Scale* with the possibility of skipping answers. For all items we asked for 'severity to eye strain' (negligible - marginal - significant - critical - n/a) and the 'occurrence frequency' (incredible - improbable - remote - frequent - n/a).

3.2 Results

4 out of 5 developers rated 'long-time use' of HMDs within one VR session as a marginal eye strain factor, and one developer rated it as a critical factor. 1 participant indicated that eye strain may occur in sessions longer than 15 minutes while the other participants could not give clear statements to the question on how fast HMD users experience eye strain within one session. Answers to all further questions are summarized in a table in figure 2.

3.3 Discussion

Only the results yielded by the response of the five developers were available at the time of submission, and more participants for definite results are awaited. However, first insights and tendencies are observable. The results show high consensus in a high occurrence frequency of 'Position Tracking Error' and 'Jitter', 'Flicker' and 'Blurred Vision'. 4 out of 5 participants rated the occurrence of the 'vergence-accommodation' conflict as frequent and 1 participant as improbable. Since this is an issue accompanying all HMDs by nature of their design, developers awareness even of significant issues may not always be present. Discordant ratings such as the ratings for occurrence frequency of 'Binocular Asymmetries in general' and the ratings for the general 'Occurrence frequency of eye strain factors in your development' are a further indicator for this assumption.

4 Conclusion

In our paper we summarized known factors for *asthenopia*, presented the methods that measure the effects of *asthenopia* and its causes. In addition we conducted an online survey that should help us to reveal the awareness about factors that trigger *asthenopia* among developers and their estimation of the visual stress produced by the factors. We have shown that there is extensive literature about the factors that create visual stress and also different methods to measure either the factors causing the stress or the user reaction in a subjective or objective manner. But as our online survey suggests, developers awareness and knowledge about *asthenopia* may be limited (discordant ratings such as the ratings for occurrence frequency of 'binocular Asymmetries in general and the ratings for the general 'occurrence frequency of eye strain factors in your development). This is crucial as we do not expect the end-user to have more advanced knowledge compared to a professional. Some possible dangers like issues relating to the rendering of a system are treated by modern engines like Unreal or Unity, and yet they still do not encompass all failures, as there are still some issues reported in our survey. These are namely 'position tracking error and jitter'. 'Flicker' and 'blurred vision' are due to high occurrence frequency and partly high ratings for the degree of severity of eye strain. In order to prevent health issues or unsatisfactory experiences, we propose the usage of EEG in combination with eye-tracking. Eye-tracking is one of the major key features needed for future HMDs either to enable foveated rendering or to make the rendered picture more realistic for the user, e.g. by focus blur or supporting vergence movings of the eyes. Therefore we argue that this technology will be revealed in future HMDs. EEG is also not common in HMD today, the operationality was shown in related work [13] and there is already a commercial HMD with integrated EEG available [2]. Methods to use these systems in order to detect visual stress are missing and these systems offer the potential to give feedback to developers in real time.

Therefore the goal of our work is the specification of critical and relevant causes for asthenopia. We started with research on related work describing the criticality of different causes for asthenopia for the user. Further, we gained insight into the field by asking developers for observations of causes in their everyday work. With this backdrop we want to define or review repeatable test cases that provoke the stress in a distinct way. We plan to record a dataset needed for machine learning as we do not expect (1) to be able to find a clear signal for all cases in terms of describing the *event related potential* of the EEG by amplitude over time, and (2) it may be harder to find this signal outside of a lab study with classical detection methods. The number of datapoints for the machine learning algorithm also needs to be very large, and the distribution of these systems will provide us access to a greater amount of data we would use for training in the future. This approach will pave the way to be able to prevent users from visual discomfort and unsatisfactory experiences.

[2]http://looxidlabs.com/

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