Visual Fatigue Examination on Static and Dynamic Virtual Environment

Laras Swandayani and Adithya Sudiarno
Industrial and System Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
larasswandayani@gmail.com, adithya.sudiarno@gmail.com

Abstract

Many companies are competing to develop Virtual Reality (VR) because they see it as a great industrial potential. However, the acceleration of VR applications penetration does not come up with customer experiences development. Fatigue, which generated by eye conflict, is still becoming a natural problem that the VR user feels. While actually, this condition can be minimized by adjusting the parallax. Furthermore, no particular guideline has stated the maximum duration of using VR to prevent visual fatigue. This research is aimed to validate the effect of the VR environment and the task inside towards visual fatigue. Objective and subjective measurement is applied respectively into the static and dynamic scenario. Critical Flicker Fusion Frequency, Eye Fixation, Eye Saccades, and Eye Blink Rate are used to measure the eye capability to handle the fatigue. This research is expected to find out the relationship between parallax inside the VR environment to visual fatigue. This result can be used by the VR developer as a concern when developing VR in the future. This research contributes to generating the exact maximum duration of VR used as a guideline to prevent visual fatigue while using the VR.

Keywords
Dynamic, Parallax, Static, Visual Fatigue, Virtual Reality.

1. Introduction
The popularity of virtual reality and 3D TV generates the need of conducting an extensive research to find out the effect and maximum duration of human-VR interaction to ensure the effectivity and comfortability of user (Vinnikov et al. 2016). This type of research will become an urgent need when user aware of the effect of the long period us of VR. There are no available guidelines to be used as the fundamental of VR implementation so far. By now, VR developer-only gives a suggestion of duration which not based on scientific research. This issue would also be related to the user's safety because VR has implemented in many essential applications, such as in the surgical area.

Visual fatigue is an effect of the accommodation-vergence conflict that arises when observer viewing stereoscopic 3D display (Vinnikov et al. 2016). Eyes are tending to perceive visual fatigue because they are difficult to merge the left and right retinal images with binocular parallax when viewing stereoscopic images (Emoto et al. 2006). One of the main causes of unwanted effects of interacting with 3D TV is depth distortion (Kim et al. 2011). This condition shows the importance of generating natural images by adjusting the depth distortion's amount. The power of 3D impact can be adjusted by changing the parallax, but excessive parallax can trigger the visual fatigue occurred (Kim et al. 2011).

Basically, the interaction between human and virtual environment can be generated in a static and dynamic environment. This research hypothesizes that there is some different effect of visual fatigue between them. This statement is supported by the initial condition of static and dynamic that have different workload to the user. The objectives of conducting this research are to know the fundamental concept to understand whether fatigue has the same degree for static and dynamic.

2. Methods
An extensive literature review was carried out to introduce the fundamental concepts and provide an overview of visual fatigue measurement.

3. Data Collection

This chapter contains the summary of literature review as shown in Table 1.

Table 1. Literature Review Summary

Study (authors, year)	Stimuli	Type of Measurement	Independent Variables	Measurement indicators	Number of Participant	Group of Participant	Objective	Researchable Gaps	Result
(Zhou et al. 2019)	Shifted-S3D-Image-Database (SSID)	Subjective visual discomfort scores Eye tracking data		Accuracy Heat map Eye fixation	24	between 21 and 27, avg 23,6			
(Wang et al. 2015)	LED lighting tubes and fluorescent tubes	Subjective responses Task performance		Reading accuracy, rate, and efficiency	12	23 to 34 years old	analyze the lighting influences of several LED conditions towards visual fatigue,		Visual fatigue affected by illuminance, CCT and the type of light source. Visual fatigue can be compressed by LED lighting. It is better than using fluorescent lighting
(Iatsun, Larabi, and Fernandez-Maloigne 2015)	2D video 3D video	Eye movement		Questionnaire Visual gaze	20	22 to 30	Knowing the symptoms differences between 2D and 3D model towards visual fatigue and knowing the impact of them to visual characteristics and the accumulation of visual fatigue.		Content type and duration generates significant impact towards video fatigue accumulation and visual functions
(Kim D. et al. 2011)	Random dot stereogram		Moderate Video Low Video	Eye blink	6		Measuring visual fatigue		Moderate visual fatigue generates greater impact

Study (authors, year)	Stimuli	Type of Measurement	Independent Variables	Measurement indicators	Number of Participant	Group of Participant	Objective	Researchable Gaps	Result
							induced by stereoscopic videos		(increasing) to eye-blinks rate rather than the low visual fatigue. The value will be decreasing more in the second half of the session.
(Emoto, Niida, and Okano 2006)	Stereoscopic TV								Visual fatigue generated by extreme horizontal binocular parallax and intermittent changes in parallax
(Vinnikov, Allison, and Fernandes 2016)	3D virtual scenes	Subjective Visual Function Oculomotor function Eye data	Age Depth cues DOF		9 young adults and 7 older adults	Younger and older adults	evaluate the role of gaze-contingent DOF on subjective experience of the 3D scene		The depth quality decreasing by the value of DOF. It is for people who don't have accommodation capability in real life. DOF is not a straightforward solution for accommodation-convergence conflict.
(Lin et al. 2008)	Visual Basic 6.0 experimental interface		Display factor and vibration factor	accuracy, reaction time, CFF, visual acuity, and subjective measurement.	10		Investigate the relationship between vibration and reading performance. Identify task of numeric characters on the visual display		Reaction time, accuracy and visual fatigue influenced by the vibration's frequency and magnitude.

Study (authors, year)	Stimuli	Type of Measurement	Independent Variables	Measurement indicators	Number of Participant	Group of Participant	Objective	Researchable Gaps	Result
							terminal (VDT).		
(Bahill, A. T. and Stark, L. 1975)				Saccades					To prove that glissades, overlapping saccades, and low-velocity, non-Main Sequence saccades are generated by fatigue of the saccadic eye movement system; to show that small saccades can generate fatigue; to demonstrate that as few as 30 saccades of SO-deg magnitude may generate significant effects of fatigue; to recommend the variations in neurological control signals associated with fatigue; and to recommendation future clinical and research applications of recording the eye movements
(Komogortsev and Abdulin 2015)	Dot on a black screen	Eye tracking Questionnaire		Fixation, Saccades, Subjective scores	36	19 – 31 years with an average	to investigate eye fatigue detection capabilities of	assessing if the achieved metric sensitivity to	the Fixational Qualitative Score, has better

Study (authors, year)	Stimuli	Type of Measurement	Independent Variables	Measurement indicators	Number of Participant	Group of Participant	Objective	Researchable Gaps	Result
						age of 21.8 (SD=3.2)	the eye movement-based metrics called behavioral scores	fatigue can be kept on the low cost, low sampling frequency of eye tracking equipment. another objective metrics with high eye fatigue sensitivity	sensitivity to eye fatigue than the existing saccade-based metrics,
(Hoffman et al. 2008)	Random dot stereograms						to investigate how the relationship between accommodation- and vergence-specified distances influence visual performance and fatigue.		
(Kim, Choi, Choi, et al. 2011)	Video	Eye blink Eye movement	Type of video	The incremental number of visual fatigue accumulation influence the saccade movement of the eye (decreasing) and the number of eye blink (increasing).			Monitoring visual fatigue system based on eye-blink detection and eye-movement.	Automatic depth adjustment can control the amounts of parallax based on the results of visual fatigue monitoring system.	Visual fatigue increased by the decreasing number of saccade movement.
(Cheng et al. 2018)	E-books	Eye flicker frequency Subjective measurement	Reading materials Reading durations		24	11.75 (± 0.4) years	examines how reading-related factors influence the visual fatigue	examine the relationships between reading content and	the different reading materials have no significant difference in

Study (authors, year)	Stimuli	Type of Measurement	Independent Variables	Measurement indicators	Number of Participant	Group of Participant	Objective	Researchable Gaps	Result
							that incurred when reading both e-books and paper-based book	reading ambient factors	terms of affecting visual fatigue levels. Long periods of reading without proper rest should be avoided
(Walther, Larsen, and Fry 2001)	Daily activities and table tennis VR simulation	SSQ	Group of participants		62	VR and control group	investigating how HMDs may also lead to visual and cognitive aftereffects	Effect and cause determination of visual and cognitive changes	larger changes in accommodation were linked to more severe sickness symptoms suggesting that decoupling accommodation and vergence could be more adverse than previously thought
(Shi et al. 2011)	Letter visual chart	Pupil diameter size, Blinking frequency, accommodation -convergence time Eyelids open value Reaction Time Subjective ratings	Lighting conditions. Work period		5	mean age of 24	to investigate the visual fatigue diversity towards the static and dynamic lighting environment for the VDT work		Preventing visual fatigue effectively can be maintained by adjusting the static and dynamic lighting conditions
(Yoon et al. 2020)	Gameplay	Accommodative factors Subjective ratings	Game modes. Methods types		23		To examine the differences in refraction, accommodative factors, visual parameters, and subjective symptoms by		there was a significant increase in the near point of accommodation (NPA), convergence

Study (authors, year)	Stimuli	Type of Measurement	Independent Variables	Measurement indicators	Number of Participant	Group of Participant	Objective	Researchable Gaps	Result
							using two types of virtual reality (VR) content with depths of perception variations.		(NPC), and subjective symptom scores after the immersive mode
(Duffy and Alan 2002)	Virtual machine illustration	Visual performance Eye fatigue questionnaire	background–foreground luminance ratios		20		to specify whether differences in eye fatigue and visual performance can be shown under varying virtual industrial lighting conditions		In virtual environment, there is a significant difference in performance and eye fatigue with varying virtual light conditions
(Richard et al. 2012)	Ball in a projected virtual screen	Number of catches Hand ball distance	Ball condition Group of participants		15	Grouping based on conditions	Knowing the impact of DVFs towards human performance by analyzing ball catching and archery.		a significant positive effect of the DVFs, that could be either classified as “performance-assisted” or “learning-assisted.”

4. Discussion

Visual fatigue has been researched in several published journals, but the scope and area of interest are different. Some researchers use 2D stimuli or 3D stimuli presented in TV or monitor, but some are represented through a projected-based interface. The stimuli differences create many types of stimuli and instrument to make it. Random dot stimuli are one example of simple stimuli. The stimuli can be presented in a static and also dynamic environment. The workloads given to the user are different between the static and dynamic environment. The interaction between user and stimuli can be conducted by using computerized hardware or using more advanced technology that can directly interact with the stimuli.

How to measure visual fatigue is another challenge in this area. Visual fatigue frequently measured subjectively. The subjective measurement conducted by giving the user a questionnaire after they interact with the stimuli. The questionnaire can be measuring the symptom related to eye un-comfortability to eye fatigue, or even motion sickness sometimes. But in scientific research, we are attempted to measure fatigue in a quantitative way. Some objective approach is used to balance the need of quantitative measurements, such as Critical Flicker Frequency (CFF), eye movement, eye blink rate, etc.

Critical Flicker Frequency (CFF) is a measurement conducted using Portable CFF measurement. The difference between the mean value of CFF before and after some interaction is used as the critical measurement point. This value is generated from the informed point when the user finds the stable flickering light from the measurement. From the bottom-up strategy, the user should look for when the light is starting to flickering for the first time. This strategy is involving low-frequency flickering light as the starting point. On the other hand, the user should look for the point when the flickering light is not flickering anymore in the top-down strategy. This is the point where the user feels that the flickering light remain stable. The visual fatigue is generated when the mean CFF value from the interaction decreased.

Eye movement consists of several types of data. The most used eye movement data that can indicate visual fatigue is eye fixation and eye saccades. Eye movements can show the interest of humanity. When the visual attention was getting slower, it can be a cause of visual fatigue. Saccades can be defined as the movements of an eye between two eye fixations. Eye saccades movement will be decreased when the visual fatigue increases. Meanwhile, fixation is a metric that explains the state of the eye when the eye is relatively held on to a place, and then the visual system can record the detailed information about that. Two kinds of fixation data could get from the eye movement records, such as fixation duration and fixation count or frequency. Before analyzing, the data should be filtered using the median to avoid the outlier influence.

The subjective scores are used by giving some questions related to eye conditions. The questions should be made by looking at the eye fatigue symptoms. To provide the evaluations, the subjects should provide some ratings subjectively. The ratings are provided on a yes or no scale or Likert scale. The value of the ratings represents their feelings at that time. That measurement is used as the dependent variable that can indicate visual fatigue. Some of the reviewed papers use different dependent variables to check the relationship of some variables related to visual fatigue. The independent variable should be compatible with the research objective. The experimental setting also should be made suitably.

5. Conclusion

Those literature review can be used as the base importance of conducting a research that evaluating the visual fatigue which can be generated in static and dynamic 3D VR environment. Objective and subjective measurement should be run simultaneously to yield the optimum result of the hypothesis. Critical Flicker Frequency (CFF), Eye movement data and eye blink rate is some most used parameter to measure visual fatigue. Meanwhile, for the subjective measurement we can use eye fatigue questionnaire.

References

Bahill, A. T., and Stark, L., Overlapping saccades and glissades are produced by fatigue in the saccadic eye movement system, *Experimental Neurology,* vol. 48, no. 1, pp. 95–106, 1975.

Cheng, P.Y., Su, Y.N., Chien, Y.C., Wu, T.T., Huang, Y.M., An investigation of visual fatigue in elementary school students resulting from reading e-books, *Journal of Internet Technology,* vol. 19, no. 5, pp. 1285–92, 2018.

Duffy, V.G., and Alan H.C., Effects of virtual lighting on visual performance and eye fatigue, *Human Factors and Ergonomics In Manufacturing,* vol. 12, no. 2, pp. 193–209, 2002.

Emoto, M., Niida, T., and Okano, F., Repeated vergence adaptation causes the decline of visual functions inwatching stereoscopic television, *NHK Laboratories Note,* no. 501, pp. 328–40, 2006.

Hoffman, D. M., Girshick, A.R., Akeley, K., and Martin S.B., Vergence-accommodation conflicts hinder visual performance and cause visual fatigue, *Journal of Vision,* vol. 8, no. 3, pp. 1–30, 2008.

Iatsun, I., Larabi, M.C., and Fernandez-Maloigne, C., Investigation and modeling of visual fatigue caused by S3D content using eye-tracking, *Displays,* vol. 39, pp. 11–25. 2015.

Kim, D., Choi, S., Choi., Shin, H., Shon, K., Visual fatigue monitoring system based on eye-movement and eye-blink detection, *SPIE Proceedings 7863 Stereoscopic Displays and Applications XXII*, United States, California, 2011.

Kim, D., Choi, S., Choi., Shin, H., Stereoscopic visual fatigue measurement based on fusional response curve and eye-blinks, *17th DSP 2011 International Conference on Digital Signal Processing*, Greece, Corvu, 6-8 July 2011.

Komogortsev, O. V., and Abdulin, E., User eye fatigue detection via eye movement behavior, *Conference on Human Factors in Computing Systems - Proceedings* vol. 18, pp. 1265–70, Republic of Korea, Seoul, 2015.

Lin, C.J., Yao Hung, H., Hsiao Ching, C., and Chen, J.C.,Visual performance and fatigue in reading vibrating numeric displays, *Displays,* vol. 29, no. 4, pp. 386–92, 2008.

Richard, P., Naud, M., Inglese, F., and Richard E.,, Modeling dynamic interaction in virtual environments and the evaluation of dynamic virtual fixtures, *Presence: Teleoperators and Virtual Environments,* vol. 21, no. 3, pp. 321–37, 2012.

Shi, X., Li, H., Mi, W., Chang, D., and Zhang, Y., Visual fatigue diversity research of static and dynamic lighting environment, *2011 IEEE 18th International Conference on Industrial Engineering and Engineering Management, IE and EM 2011* (PART 1): pp. 291–94, China, Changchun, 3-5 September 2011.

Vinnikov, M., Allison, R.S., and Fernandes, S., Impact of depth of field simulation on visual fatigue: who are impacted? And how?, *International Journal of Human Computer Studies,* vol. 91, pp. 37–51, 2016.

Walther, T., Larsen, M.P., and Fry, E.S., Ep R in T Ep R, *Pulse*, pp. 1–4, 2001.

Wang, Q., Xu, H., Gong, R., and Cai, J., Investigation of visual fatigue under LED lighting based on reading task, *Optik,* vol. 126, no. 15–16, pp. 1433–38, 2015.

Yoon, H.J., Kim, J., Park, S.W, Heo, H., Influence of virtual reality on visual parameters: immersive versus non-immersive mode, *BMC Ophthalmology,* vol. 20, no. 1, pp. 1–8, 2020.

Zhou, J., Wang, L., Yin, H., and Bovik, A.C., Eye movements and visual discomfort when viewing stereoscopic 3D content, *Digital Signal Processing: A Review Journal,* vol. 91, pp. 41–53, 2019.

Biographies

Laras Swandayani is a dual degree student of Master of Industrial and System Engineering in the Institut Teknologi Sepuluh Nopember, Surabaya and Industrial Management, National Taiwan University of Science and Technology, Taipei. She got the S.T. degree in Industrial Engineering in the Institut Teknologi Sepuluh Nopember, Surabaya.

Adithya Sudiarno is a Lecturer Director of Industrial and System Engineering in the Institut Teknologi Sepuluh Nopember, Surabaya. He earned his S.T., and M.T., in Industrial Engineering, Institut Teknologi Sepuluh Nopember, Surabaya. His competencies include but not limited to Occupational Safety and Healthcare System Management, Human Factors, Product Innovation.