An Evaluation of Dichoptic Tonemapping in Virtual Reality Experiences

Martin Mišiak*†, Tom Müller†, Marc Erich Latoschik *, Arnulph Fuhrmann †

* University Würzburg, HCI Group
martin.misiak.89@gmail.com
marc.latoschik@uni-wuerzburg.de

† TH Köln, Computer Graphics Group
tom_vincent.mueller@smail.th-koeln.de
arnulph.fuhrmann@th-koeln.de

Abstract: Recent research has shown that dichoptic tonemapping can invoke an increased sensation of depth. However, many aspects of the technique still remain unexplored in the context of Virtual Reality. In this work, we investigate the impact of dichoptic tonemapping on user presence, depth-based task performance, as well as its potentially adverse influence on cybersickness. While no significant effect was found on user presence, our results show that dichoptic tonemapping has a higher probability of increasing cybersickness symptoms. No clear conclusion could be made regarding its interaction with task performance.

Keywords: Virtual Reality, Tone Mapping

1 Introduction

Dichoptic tonemapping aims at increasing the overall contrast and detail level of a scene, by presenting two differently tonemapped images to the viewer. While each image is shown exclusively to one eye, the combined binocular percept is theorized to contain the luminance ranges of both images. In addition to this quality, recent research has shown that dichoptic tonemapping can also lead to an increased sensation of subjective depth [WC21][ZKD+19]. Important aspects of this technique, such as its impact on presence or cybersickness, have not yet been thoroughly explored in the context of Virtual Reality (VR). In our work, we address this gap via a user study, where a dichoptic and non-dichoptic group are compared. In addition, we examine if the subjective sensation of depth also extends to an improved performance in depth-based tasks.

2 Experiment

To explore the effects of dichoptic tonemapping on depth-based performance, a between-subject study is conducted. In it, participants complete multiple iterations of a block matching game (figure 1), where a moveable block must be aligned directly above a randomly positioned opening in a dense 11x11 grid of blocks. Three difficulty levels are implemented, with each level increasing the vertical distance between the moveable block and the underlying grid. The study takes place in the Amazon Lumberyard Bistro scene. To account for different luminance distributions which could affect the dichoptic tonemapping result, the Bistro

Figure 1: To study the influence of dichoptic tonemapping, participants complete a block matching game in two environments (Street, Cafe). One participant group is presented with dichoptically tonemapped image-pairs. These images exhibit different contrast curves for each eye (left). The goal of the game is to position a moveable block directly above a random opening in the underlying plane. The game is divided into three difficulty levels, where each level increases the block's distance from the target surface (right).

scene is divided into an interior (Cafe) and exterior (Street) part. Our study is implemented in Unity and presented on a HTC Vive Pro. The dichoptic tonemapper uses the DiCE technique by Zhong et al. [ZKD$^+$19]. A parametrization of four interleaved tone curve segments is chosen to account for the dynamic range of the employed VR display [CFFM19]. Eighteen individuals (9M, 9F) were recruited for the experiment. All participants had normal or corrected to normal vision and were naive to the goals of the study. The participants were equally divided into a dichoptic (DTM) and a non-dichoptic (TM) test group. The images presented to the TM group were tonemapped using the ACES[1] technique. The images for the DTM group have been additionally processed with the DiCE technique.

At the start of the experiment, participants fill out a pre-immersion VRSQ[KPCC18] questionnaire, and are placed into an introductory environment. After a short oral explanation of the matching task and a subsequent training session, the overlapping binocular field of view is determined for each participant. This information is used to mask out the dichoptic operator towards the monoscopic peripheral view regions. Once finished, participants start the experiment in one of two randomly chosen environments (Cafe or Street). Each participant performs 45 repetitions of the block matching game, with 15 repetitions for each of the three difficulty levels. The same procedure is repeated for the second environment. The experiment is concluded with an IPQ [SFR01] and an additional post-immersion VRSQ questionnaire.

[1]https://github.com/ampas/aces-dev

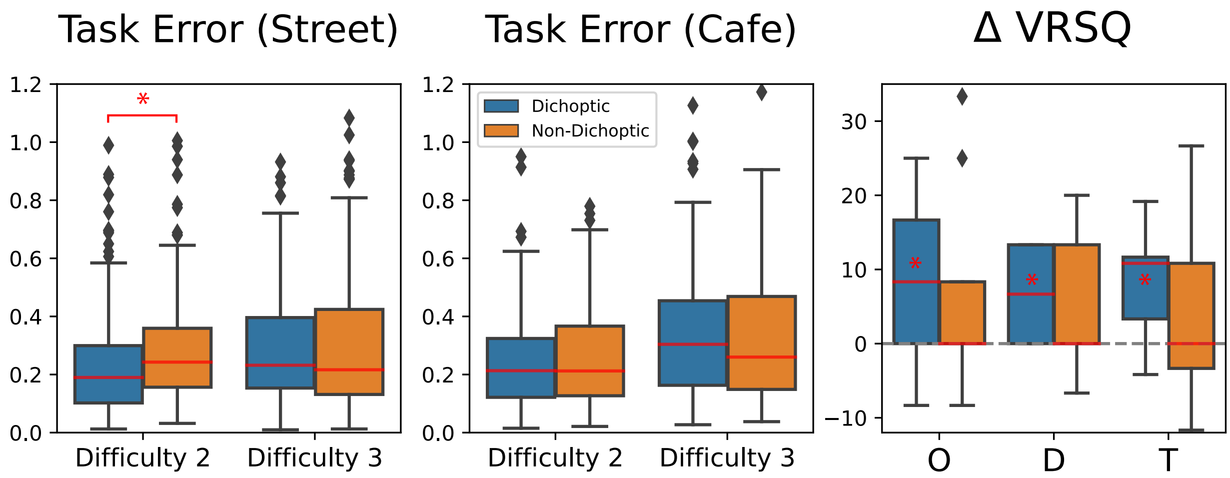

Figure 2: Left and middle: Task Error for the block matching task in the Street and Cafe environment. Right: Differences between pre- and post-immersion VRSQ scores. The sub-scores for oculomotor(O) and disorientation(D) are plotted along the total(T) score.

3 Results

Performing a Mann-Whitney-U-Test on the IPQ results did not show any significant influence of dichoptic tonemapping on Spatial Presence ($U = 981.5$, $p = .797$), Realism ($U = 490.5$, $p = .0711$) or General Presence ($U = 35.0$, $p = .6418$). A significant difference was found for Involvement ($U = 426.0$, $p = .0105$), where the dichoptic condition scored lower ($M = 2.194$, $SD = 1.524$) than the non-dichoptic one ($M = 3.111$, $SD = 1.505$).

Since the participants perform two subsequent rounds of the matching game in different environments, it is important to exclude any potential learning effects. A Wilcoxon signed-rank test revealed a significant improvement in task performance between the first and second trial for the first difficulty level ($Z = -5.0271, p < .001$). The data for this difficulty will therefore be discarded from further analysis. The task performance is measured by computing the Euclidean distance between the block's position and it's ideal placement. A Mann-Whitney-U-Test showed a significant difference between both tonemapping conditions for the second difficulty level performed in the street environment ($U = 7377.0$, $p = .009$) (figure 2 left). The task error was lower for the dichoptic group ($M = 0.241$, $SD = 0.195$), as opposed to the non-dichoptic group ($M = 0.284$, $SD = 0.198$).

To assess the level of induced cybersickness, the difference between the post- and pre-immersion VRSQ sub-scores is computed (figure 2 right). A one-sample t-test confirmed that all three Δ-scores of the dichoptic condition significantly deviate from zero - (Oculomotor: $t(8) = 2.45$, $p = .04$), (Disorientation: $t(8) = 3.465$, $p = .008$), (Total: $t(8) = 3.127$, $p = .014$). This was not the case for the non-dichoptic group.

4 Conclusion

Our findings suggest that dichoptic tonemapping may improve task performance, as evidenced by improved block alignment in the street environment for the second difficulty level. However, it is not clear if this improvement is attributable to an increased depth sensation, or if it is the result of a more appropriate contrast ratio provided by one of the two component images generated by the dichotpic tonemapper. In future work, we would like to address this specific question.

The conducted experiment did not reveal any benefits of dichoptic tonemapping on user presence. While no significant difference is found for the categories of Spatial Presence, Realism and General Presence, Involvement is rated significantly lower for this condition. Prior work has used a within-subjects methodology to highlight the increase in subjective depth perception. We hypothesise the effect to be rather subtle regarding its impact on user presence, making it more difficult to detect with a between-subjects methodology.

In regards to cybersickness, our results clearly show that the use of dichoptic tonemapping can lead to an increase in cybersickness related symptoms. To precisely quantify the amount, however, a larger sample size is required.

For future work, we would like to investigate the use of this technique for specifically visualizing high dynamic range effects such as fire and other emissive surfaces. Exploring the use of a local dichoptic tonemapping operator based on eye tracking would be an interesting direction for future work as well.

References

[CFFM19] Olaf Clausen, Gregor Fischer, A Furhmann, and Ricardo Marroquim. Towards predictive virtual prototyping: color calibration of consumer vr hmds. In *16th GI AR/VR Workshop*, pages 13–24, 2019.

[KPCC18] Hyun K Kim, Jaehyun Park, Yeongcheol Choi, and Mungyeong Choe. Virtual reality sickness questionnaire (vrsq): Motion sickness measurement index in a virtual reality environment. *Applied ergonomics*, 69:66–73, 2018.

[SFR01] Thomas Schubert, Frank Friedmann, and Holger Regenbrecht. The experience of presence: Factor analytic insights. *Presence: Teleoperators & Virtual Environments*, 10(3):266–281, 2001.

[WC21] Minqi Wang and Emily A Cooper. A re-examination of dichoptic tone mapping. *ACM Transactions on Graphics (TOG)*, 40(2):1–15, 2021.

[ZKD+19] Fangcheng Zhong, George Alex Koulieris, George Drettakis, Martin S Banks, Mathieu Chambe, Frédo Durand, and Rafał K Mantiuk. Dice: dichoptic contrast enhancement for vr and stereo displays. *ACM Transactions on Graphics (TOG)*, 38(6):1–13, 2019.