Applying Virtual Reality for Systematic Gaze Pattern Evaluation in Simulated Retinitis Pigmentosa Patients

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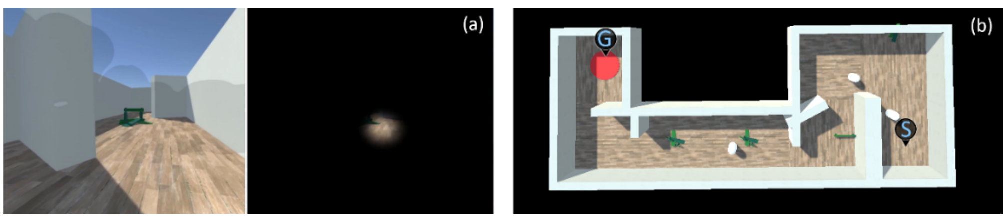

Figure 1: (a) Example of a navigation trial in virtual reality from participant's view, without (left) and with (right) simulated tunnel vision; (b) Top-down showcase of a randomly generated obstacle parkour used to test the navigation performance of the participants. S = start; G = goal.

ABSTRACT

We apply virtual reality headsets with eye tracking capabilities to evaluate new training methods for patients living with loss of peripheral vision ("tunnel vision"). It can be shown that systematic gaze patterns, taught in a virtual reality environment, are able to significantly increase the effectively perceived visual area of the participants as well as reduce the number of obstacle collisions in navigation tasks.

ACM Reference Format:
Alexander Neugebauer, Katarina Stingl, Iliya Ivanov, and Siegfried Wahl. 2021. Applying Virtual Reality for Systematic Gaze Pattern Evaluation in Simulated Retinitis Pigmentosa Patients. In *Special Interest Group on Computer Graphics and Interactive Techniques Conference Posters (SIGGRAPH '21 Posters), August 09–13, 2021, Virtual Event, USA.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3450618.3469178

1 INTRODUCTION AND MOTIVATION

Loss of the peripheral visual field – oftentimes caused by retinal diseases such as retinitis pigmentosa – has severe impact on everyday visual tasks like navigation and obstacle awareness. Further, in the current state of medicine, it is only rarely possible to restore or even just stop the progressive loss of the visual field field [Bellingrath and Fischer, 2015; Koch et al., 2015]. However, the increasing performance and accessibility of virtual and augmented reality devices in recent years allow for new approaches in both research and practical application to aid people living with such conditions [for example: Angelopoulos et al., 2019; Ehrlich et al., 2017] and even earlier studies made use of virtual environments and head-mounted devices for low-vision simulations [Apfelbaum et al., 2007; Haymes et al., 1994; Peli et al., 2000].

In a preliminary study by Ivanov et al. [Ivanov et al., 2016], retinitis pigmentosa patients underwent gaze training on a flat screen to increase the average distance covered by their gaze movements. It could be shown that after training, patients showed a significant increase in average walking speed. However, it can be assumed – and was suggested by Ivanov – that through use of the larger coverage of the visual field offered by virtual reality headsets, the effects of the gaze training can be improved. In addition, it was suggested that instead of focusing only on saccade amplitude, the training of a more systematic gaze behavior can lead to a larger effective Field of View (FoV) and a resulting increase in obstacle awareness. Thus, our study aimed to assess the potential of different patterns of eye movement (systematic gaze patterns) in a virtual reality training environment to (i) increase the effective area of perception of participants with simulated tunnel vision and (ii) maintain or improve performance in visual navigation tasks [Neugebauer et al., 2021].

SIGGRAPH '21 Posters, August 09–13, 2021, Virtual Event, USA

ACM ISBN 978-1-4503-8371-4/21/08.
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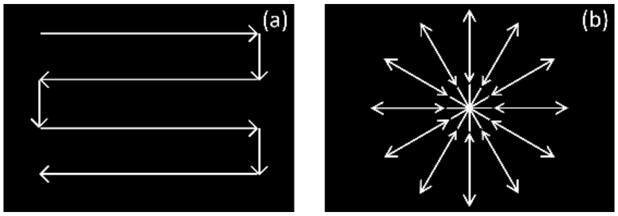

Figure 2: Visual representation of the horizontal gaze pattern (a) and radial gaze pattern (b) that participants were asked to follow during the visual task.

2 METHOD

A virtual navigation parkour (Figure 1 (b)) was created and obstacles consisting of both static and moving objects as well as objects hanging from the ceiling were implemented, requiring constant awareness of potential obstacles in all directions. We evaluated two different systematic gaze patterns, shown in Figure 2 (a) and (b), by their potential to improve the effective visual area perceived over a time average, as well as their influence on the performance in visual tasks.

Through use of eye-tracking, the image inside the virtual environment was masked in a way that simulates the loss of the peripheral Field of View caused by retinitis pigmentosa, limiting the participants' FoV to 20° (Figure 1 (a)). In an initial training sequence, participants were introduced to the systematic gaze patterns and learned to adapt to the eye movements required to follow those patterns. Afterwards, they were asked to navigate in a randomized virtual environment visualized in Figure 1 (a) and (b) while executing one of the previously trained gaze patterns. As a baseline, we also measured the navigation performance in this setup without the requirement to follow any systematic gaze pattern, meaning participants were free to use their natural gaze behavior. The order of the three conditions ('gaze pattern 1', 'gaze pattern 2' and 'no gaze pattern') was randomized. In the statistical analysis, random-intercept, random-slope linear mixed-effect models were applied for perceived area and trial duration. For collisions, a zero-inflated Poisson regression was applied.

3 RESULTS AND DISCUSSION

A total of 545 obstacle awareness task trials were evaluated with respect to the Dynamic Field of View (DFoV) – the average visual area covered by gaze over a fixed amount of time -, the number of collisions and average time per trial. The results are shown in Figure 3. It was found that the gaze pattern focusing on straight, horizontal eye movements (Figure 2 (a)) led to an overall similar or better performance than the pattern based on radial eye movements (Figure 2 (b)) and was also better accepted and described as more intuitive by participants.

Compared to the trials in which no systematic gaze pattern was applied, the trials with horizontal gaze pattern show a significant increase in the perceived visual area ($p=0.034$) and a reduction of obstacle collisions (count model coefficient estimate -1.09 with standard error of 0.16, $p<0.001$). The average duration for trials increased for both gaze patterns ($p=0.0011$ for horizontal pattern, $p=0.0017$ for radial pattern), which can partially be explained by

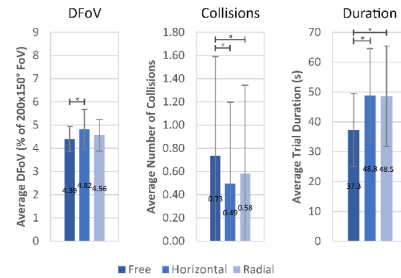

Figure 3: Comparison between average Dynamic Field of View, number of collisions, and trial duration in the three different gaze pattern conditions during navigation (*$p < 0.05$).

a shift in the speed-error tradeoff often found in psychophysical experiments.

4 IMPLEMENTATION AND FUTURE WORK

Suggested by the findings of this study, the horizontal gaze pattern will be implemented as part of a virtual reality based six-week training for both tunnel vision patients as well as visually healthy participants with simulated tunnel vision, comparing the visual performance in real-world obstacle parkours before and after the training. The results will give insights not only to the full potential of systematic gaze pattern training to improve visual performance but also to how accurate visual conditions simulated in virtual reality can represent real visual impairments in research.

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