[VR gaming: visual behavior in simulated conditions]

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Background: Partial alterations of the visual field due to local deterioration are usually referred to as scotomas. Retinal and cortical defects may result in central scotomas, which convey a loss of visual acuity in the central area. The prevalence of this visual deficit is increasing as the world's population ages. Cortically induced central visual loss usually happens due to a stroke affecting the primary visual cortex. This form of vision loss severely affects the life quality of the patients, and activities such as safely crossing the street, which involves correctly tracking in-coming cars, become challenging. Being affected by a central scotoma means that the normal mechanism of foveation is disrupted. Patients have to re-learn how to gaze by using their peripheral vision. Similar behavior can be induced in normal subjects under simulated conditions using gaze-contingent paradigms that occlude the central part of vision (Bertera, 1992; Pidcoe and Wetze, 2006; Kwon et al., 2013). Studies involving both patients and healthy participants have shown that preventive attention placement can lead to a better target placement in relation to central visual loss (Altpeter et al., 2000; Barraza-Bernal et al., 2017). Gaze, with time, is usually directed above the scotoma and moves further away from the target, outside the scotoma boundaries (Barraza-Bernal et al., 2017). The current study addresses salience placement before scotoma development to investigate the effects over gaze directionality and gaze-target distance when simulating advanced scotoma.

Methods: A 2D VR Pong game was developed to boost gaze performance since there are known positive effects of gaming on the neural as well as on the visual processing (Buckley et al., 2010; Chopin et al., 2019). A 3° ball with an average velocity of 21.74°/s (SD: ±0.63) moved from the left side to the right one and vice versa, within a 2D plane while randomly changing its vertical direction. Subjects were requested to keep the ball inside the playing area with the help of two paddles, positioned on the left and right-side area and that could be controlled by the subject input through an Xbox controller using the left and right joysticks. If the ball exited the play area, participants had to restart the game. During the game, the ball changed color at random intervals, and the participants were asked to press an additional button whenever they observed a change in the ball's color. This subtask would increase their score and, therefore, their motivation in keeping the target visible. Each participant had a 15 min long trial, divided into a 5 min block.
Four participants were tested in 3 conditions: normally sighted, salience augmentation of scotoma simulation and central scotoma. In the normal condition, no simulation was used to play the game. For the second condition, the integrated eye-tracking of the HTC Vive Pro Eye was used to simulate a binocular gaze-contingent scotoma that covered the central 12°. Additionally, a gaze-contingent concentric 2° ring with a 27° diameter was presented around the circular scotoma. The ring was applied to the dominant eye only. A stimulus presented in the periphery and only to one eye is known to attract the gaze towards its position; it induces a popping-out effect, calling upon mechanisms of selective attention (Zhaoping, 2008). Attracting the eyes towards the peripheral cue meant that the target would start to be positioned more and more distant from the simulated scotoma. In the third condition, like in the previous one, a gaze-contingent central scotoma was presented to investigate the effect of augmentation over gaze direction and gaze distance to the target, but in this case, no augmentation was included. The effect over the median distance between gaze and target was set as a benchmark, and the different conditions were analyzed using the non-parametric Kruskal-Wallis test. These results were further controlled with a FWER test (Dunn-Šidák). To show whether a significant change in gaze behavior was followed by a re-direction of the eyes positions, a polar histogram was used to plot gaze-target direction as a function of different trials to detect known effects of training across trials (Kwon et al., 2013).

Results: The Kruskal-Wallis test found that there is a significant difference between the three conditions ($\chi^2(2) = 7.2$, $p=.03$) and the post-hoc Dunn's revealed that the scotoma induced significant changes in the gaze placement in relation to the target ($p= .02$) compared to the normal condition. A median distance of 6.26° between gaze and target was achieved. Polar histograms revealed that augmented scotoma induced an upwards directionality effect across trials which was kept and became stronger in the scotoma condition (Figure 1).

Conclusion: Salient allocation can rapidly and efficiently induce changes in gaze direction, which have a significant influence over target positioning away from the scotoma. Even if limited by a small number of participants, these results confirmed previous findings in a VR gaming experience after only 15 minutes of training. Therefore, VR gaming could potentially be applied in the future to train vision of patients with advanced visual loss that could be stimulated with salient augmentation.

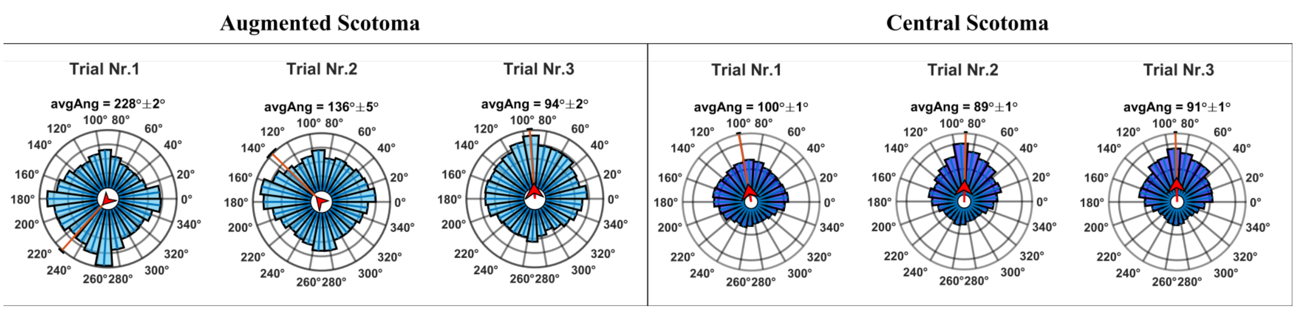

Figure 1. Polar histograms are representing the gaze direction in relation to the target. Red direction line indicates where the gaze was positioned, above the target, upwards direction, below the target, downward direction, left or right, leftwards, and rightwards direction, respectively. During the augmentation, there is an increase in the upwards direction that is maintained and re-enforced in the scotoma condition.

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