A Study on Contextual Task Performance of Simulated Homonymous Hemianopia Patients with Computational Glasses-based Compensation

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ABSTRACT

People with Homonymous Hemianopia (HH) suffer from losing ipsilateral half side of visual field in both eyes, which results in failing to obtain visual information in the lost field. Making using of the remaining of the visual field, the state-of-the-art studies proposed Overlaid Overview Window (OOW) and Edge Indicator (EI) on the basis of Augmented-Reality (AR) glasses for compensation. However, experiments conducted in these studies investigate user performance with tasks involving events in lost field or remaining field singly. On the other hand, both studies recruited normal individuals for mock experiment, while their way to simulate HH, which requiring the participants to fix their view angles, were not practical to real HH patients. In this study, we conduct a contextual information experiment to investigate the user performance involving in the task requiring the information across both the visible and invisible sides of HH, with the compensation of OOW and Flicker-based EI (FEI). At the same time, we also recruit volunteers with normal vision for mock experiment, while the participants in our study are allowed to move their gaze freely, because we simulate the invisible field of HH on AR glasses with eye tracking. The experiment results showed that OOW is better for the task that related to move something from the remaining FoV to the lost FoV, while FEI is better for moving something from the lost FoV to the remaining FoV.

CCS CONCEPTS

• **Computing methodologies → Mixed / augmented reality**.

KEYWORDS

Visual field defect, Eye Tracking, Contextual, Simulated Homonymous Hemianopia, Augmented-Reality

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1 INTRODUCTION

Homonymous Hemianopia (HH) is one kind of diseases which is caused by lesions of the retrochiasmal visual pathways, i.e., lesions of the optic tract, the lateral geniculate nucleus, the optic radiations, and the cerebral visual (occipital) cortex [Biousse et al. 2017]. People with HH suffer from visual field defect, losing either the two right- or left-half parts of the visual fields of both eyes. The number of patients with HH is reported to account for 0.8% of the population aged 49 years or older [Gilhotra et al. 2002], with trauma, stroke, brain tumor, and other diseases as major factors. Fig. 1 shows a simulated view of people with normal visual field (Fig. 1(a)) and that of a patient with HH (Fig. 1(b)).

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Individuals with HH have difficulties in visual scanning and scene recognition. Due to the loss of visual field, the visual information, corresponding to defected field become invisible to HH patients [Qian et al. 2018]. In real environment, HH patients may fail to notice what is happening in the lost visual field, causing collisions with objects or walls, which reduces their Qualities-of-Life (QoL), and they may even be exposure to dangers, e.g., a hole on pavement. Therefore, it is important to provide timely notification of event occurred in the missing visual field so as to reduce the risk and improve their QoL [Denise 2002].

(a) (b)

Figure 1: Simulated view of normal visual field and Homonymous Hemianopia.

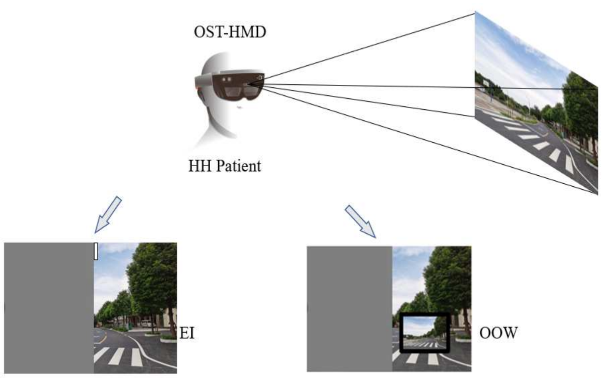

Figure 2: Overlaid Overview Window [Zhao et al. 2020] and Edge Indicator [Ichinose et al. 2022, 2020] method for alleviating the visual field limitation of HH patients using optical-see-through head-mounted display (OST-HMD)

With the development of wearable computational devices and Augmented Reality (AR) technologies, computational glasses, such as HoloLens [Bowers et al. 2004], have attracted the attention of researchers and are adopted in studies for visual impairment compensation. Regarding HH, as shown in Fig. 2, recent studies [Ichinose et al. 2022, 2020; Zhao et al. 2020] proposed to capture the scene that the user is facing to, utilizing the camera on Optical See-Through Head-Mounted Display (OST-HMD), and provide the user with compensation information via the display. Zhao et al. [Zhao et al. 2020], proposed Overlaid Overview Window (OOW) to display a downsized image of the whole scene captured by the camera in a small virtual window so that the user can regain the lost visual information. Zhao et al.'s compensation method is useful for users to obtain an overview of the normal Field of View (FoV). However, superimposing OOW on the remaining FoV may lead to further loss of remaining FoV. Ichinose et al. [Zhao et al. 2020], proposed to use brightness or flicker-based indicator placed at the edge of the remaining visual field to avoid the loss of visual field information. The method, called Edge Indicator (EI) detects the change on the lost side by chromatic aberration and optical flow of the image sequence taken by the camera on the glasses and notify the HH patients by the brightness or the blinking of the indicator. Ichinose et al. [Ichinose et al. 2022, 2020] conducted experiments to compare the compensation effects of the OOW and EI. They found there are advantages to each method depending on where the event occurs. While OOW is more effective for notifying the event occurred far from the visible visual field, EI can reduce the occlusion of remaining visual field caused by the OOW.

In the experiments of [Ichinose et al. 2022, 2020; Zhao et al. 2020], half of the OST-HMD screen was blocked with tape to simulate HH. Therefore, during the experiment, participants must move their heads while fixing their gaze at the center, which does not in consistent with the real situation where both saccade and head movement are important for orienting at a stimulus. Moreover, the task used in their experiments only require the information from the invisible side of visual field, while many of the real-world task require information from both visible and invisible sides. For example, a car may run toward visible side from invisible side and enabling a patient to tracking the car easily is very important for safety. Therefore, how to simulate HH naturally and validate the effectiveness of compensation methods for the task requiring the information on both visible and invisible sides is very important.

Based on these considerations, this study conducts a new experiment to investigate the effect of the OOW and EI for the task requiring the information across both the visible and invisible sides, namely contextual task, here after, by simulating the visual field of HH patients using eye tracking. The experiment results demonstrated that OOW is better for the task that related to move something from the remaining FoV to the lost FoV, while FEI is better for moving something from the lost FoV to the remaining FoV.

The main contributions of this paper as follow:

- A new HH simulation scheme utilizing eye tracking to dynamically set the invisible field according to gaze.
- A new user study to investigate the compensation effect of OOW and EI involving with contextual task.

The remainder of the paper is organized as follow:

Section 2: introduces the related work. Section 3: presents our HH simulation method and the contextual tasks. Section 4: describes the experiment involving with the contextual task and analyzes the experimental results. Section 5: concludes the paper with some discussion of future work.

2 RELATED WORK

Not only HH, but also many diseases will cause visual field loss, such as glaucoma, and HH can be considered as one special kind of the symptom. As a matter of fact, many studies have already been conducted to compensate for general visual field defects by providing out-of- visual field information and improve QoL of affected individuals.

2.1 Visual Field Compensation

Early studies employed optical devices, such as mirror devices, magnifying glasses, and prisms [Duszynski 1955; Goodlaw 1983], for out-of-field information compensation. Prismatic correction proposed by Peli is considered to have most effect on expanding the visual field [Peli 2000]. In their proposal, two prism segments are attached to the upper and lower sides of the lens of normal glasses to avoid central diplopia. However, the prism segments cause artificial peripheral diplopia, which reduces the effective area of user's remaining visual field. Moreover, special training is necessary for using the device effectively.

Recent advances in image capture, processing, and display technologies have led to research on using various computational technologies for compensating for out-of-field information, including studies on glaucoma [Sayed et al. 2020], tunnel vision [Martín and Peli 2002; Ola et al. 2017], and night blindness [Bowers et al. 2004]. Although these methods improve the recognition of objects in the blinded visual field or peripheral vision, they have the problem of loss of detail information because they display a scaled-down version of a wide area image.

2.2 Overlaid Overview Window (OOW)

In [Zhao et al. 2020], Zhao et al. proposed to use OOW for HH compensation, which is to use a small virtual window in the remaining visual field to display a downsized image of whole visual field. To reduce the occlusion caused by the OOW while maintaining the visibility of the content, they experimented the performance of 21 types of OOW consisting of 3 different sizes (large, medium and small) and 7 different positions (two top, three middle and two bottom). According to the experimental results, OOW of medium size, located at the Bottom 2 position which is indicated by the red frame in Fig. 3, is the optimal choice. Therefore, we use the OOW of medium size located at the Bottom-2 position in the experiment of this study.

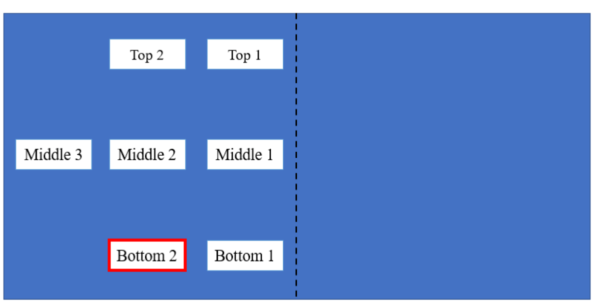

Figure 3: Most effective position for OOW

2.3 Edge Indicator

To avoid occlude the remaining visual field, which is usually already limited one, it is important to compensate the information in a way that occupies as little coverage of the visible area as possible. Ichinose et al. [Ichinose et al. 2022, 2020], proposed two different edge indicators, Brightness-based Indicator (BEI) and Flicker-based indicator (FEI). The method uses OST-HMD to display EI in the remaining FoV, compensating for the information in the missing part of the FoV by changes in the brightness and the blinking frequency, respectively. As shown in Fig. 4, the indicator is placed on the upper and lower edges of the remaining visual field to avoid occlude the central vision, and as close as possible to the lost FoV so as to response to the event in the blinded are as quick as possible. The lost visual field is divided into nine (3 × 3) regions and events in different regions are notified to the user by different brightness (BEI) or blink frequencies (FEI). In [Ichinose et al. 2022], experiments were conducted using simulated HH patients to compare BEI and FEI, and showed that FEI is more effective than BEI in terms of user response time. Therefore, this study adopts FEI and compare FEI with OOW method for contextual tasks.

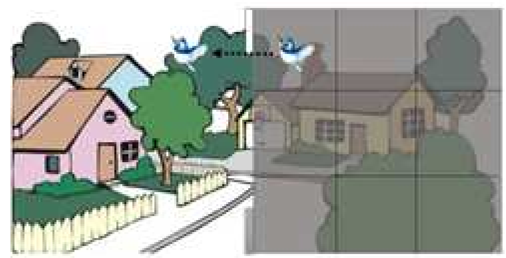

Figure 4: EI and lost visual field divided into nine (3×3) regions

3 METHODS

In this study, we design a contextual task experiment to imitate situations in daily lives that requires both information from the visible and invisible visual fields at a time. Our experiment involves the two state-of-the-art methods [Ichinose et al. 2022, 2020; Zhao et al. 2020] for HH compensation, which has been introduced in the previous part of this paper. We conduct the experiment to investigate their compensation effect in contextual tasks. Due to the difficulty recruiting real HH patients, following studies [Ichinose et al. 2022, 2020; Zhao et al. 2020], we recruit participants with normal vision and promote the experiment with HH simulation. Regarding the HH simulation, to minimize the behavior deviation from real HH patients, we adopt eye tracking to digitally simulate HH so that the participants can move their eyes during the experiment, rather than physically cover the half side of OST-HMD with black tape.

Fig. 5 shows a scene of experiment setting. A touch screen with 1920 × 1080 resolution was used in the contextual task. The distance between participants wearing HoloLens 2 and the screen was set to 50cm.

3.1 Contextual Tasks

In studies [Ichinose et al. 2022, 2020; Zhao et al. 2020], Whac-A-Mole game was introduced to evaluate the effect of compensation methods for HH patients. The interface of Whac-A-Mole game is shown in Fig. 6. In the game, there are 3×5 gray circles, representing the whole visual field without any defect, and participants were required to fix their gaze on the center point (the white dot in Fig. 6). Once the game starts, the game console randomly chooses 1 circle

Figure 5: Experiment setting

from all 15 gray circles and changes it to white, indicating that an event happened in that position, and participants were required to touch the white circle within a certain time, denoting the event has been noticed and reacted by the participant.

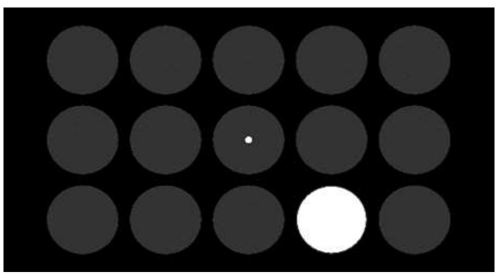

Figure 6: A Whac-A-Mole Task used in [Ichinose et al. 2022, 2020; Zhao et al. 2020]

In this study, we also adopt Whac-A-Mole game in our experiment. However, the original game can only simulate the situation that an event merely happens either in lost visual field or the remaining. The newly designed contextual task is shown in Fig. 7 and Fig. 8. Fig. 7 shows one trial of the task; within one trial, one white circle and one yellow circle are displayed at a time. The layout of circles is shown in Fig. 8. 9 circles are placed on the left and right sides, respectively. The distance between two circles on the same side is 2.0cm, vertically and horizontally; the space between left side and right side is 13.0cm on the screen; and the shortest distance between the centers of the left and right circles is 17.3 cm, and the longest distance is 44.33 cm. Before starting one trial, participants are also required to fix their gaze on the green dot in the center. Once the circles appear, they need to touch the white circle first, and drag it towards the yellow circle, so that two circles overlap; one trial should be complete within 5 seconds. If 5 seconds elapsed, or two circles overlap by more than 7.50%, current trial will be terminated and two circles disappear. Then, participants need to prepare for the next trial. The interval between two trials is 2 seconds, and 2 circles appear again but at different positions. Before the next trial begins, participants need to move their gaze back to the green dot. Considering all combinations between circles on left and right sides as well as drag directions (left to right and right to left), the total number of trials can reach to 9×9×2=162. Considering the burden on the participants involved in the experiment, we divided the 162 trials into three phases and conducted 54 trials in each phase. The order of all trials is random.

3.2 Simulation of HH using eye tracking

To simulate the perception of HH, studies [Ichinose et al. 2022, 2020; Zhao et al. 2020], put black tape on the computational glasses to occlude half of participants' FoV, and the participants were required to move their heads while keeping looking straight through the computational glasses. However, such view behavior can be unnatural to participants, obviously different from real HH patients. In this study, HH simulation is implemented with eye tracking. As a result, participants can move their gaze freely, and is much closer to real HH patients.

The simulation flow of using eye tracking is shown in Fig. 9. HH simulation is performed by creating a gray wall on the screen to hide the information supposed to be invisible to HH patients. This wall keeps adjusting its position on the screen according to users' gaze; in this study, right HH is assumed. The gaze data is obtained by HoloLens 2, and sent to the PC, which also play the role of controlling the interface on the screen.

For the event detection method in FEI, the original implementation is also changed in order to match the new HH simulation scheme. In study [Ichinose et al. 2022, 2020], event detection was based on information captured by the camera on HoloLens 2; in this study, the FEI system cannot detect events since the gray wall stops the events from being shown on the display; finally, information cannot be captured by the camera. Therefore, the information without gray wall occlusion is directly sent to OOW and FEI systems.

4 EXPERIMENT

The total number of participants was 11, including 5 males and 6 females in their 20s. 10 of the participants are with normal vision, and one is with color vision deficiency, but this did not affect the experiment.

The simulated HH view of whack-a-mole is conducted using a screen with a resolution of 1920 × 1080. Gaze information is computed in real time through computational glasses (HoloLens 2, Qualcomm Snapdragon 850, 2 IR cameras, 52° FoV). Participants were seated comfortably 50 cm away from the display. The practice was conducted until the participants were sufficiently familiar with the FEI and OOW, as well as the Contextual Task, to avoid influence to the experimental results.

4.1 Evaluation Metrics

As quantitative evaluation indices, the success time (s), which indicates the time from displaying 2 circles to they overlap; and the number of failed trials are counted in this study. For the success time, the total time of all trials is used; trials that fail to overlap within 5 seconds are counted as 5 seconds. For the number of failures, we simply count the number of trials that participants failed to make two circles overlap within 5 seconds. The NASA-TLX [Hart and Staveland 2008] is used as the subjective evaluation, where 6 indices (mental demand, physical demand, temporal demand, performance, effort, and frustration level) were evaluated through a questionnaire. Smaller values of these indices show smaller subjective workload in a task.

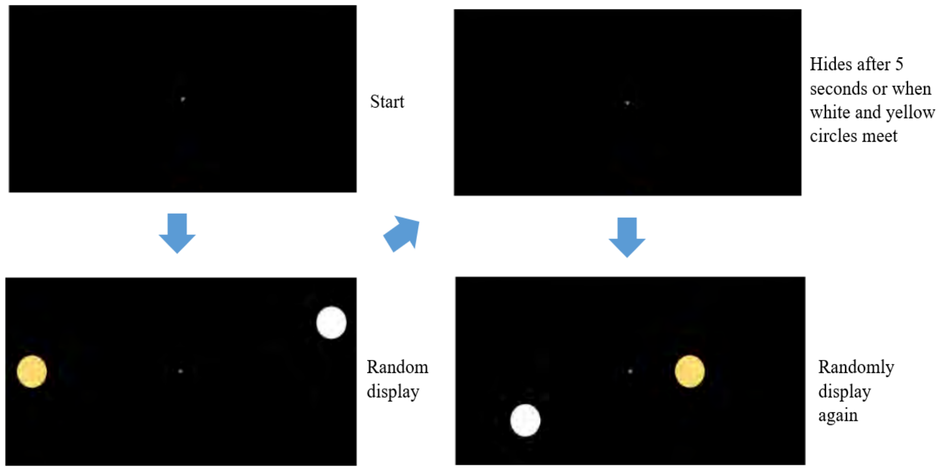

Figure 7: Contextual task flow

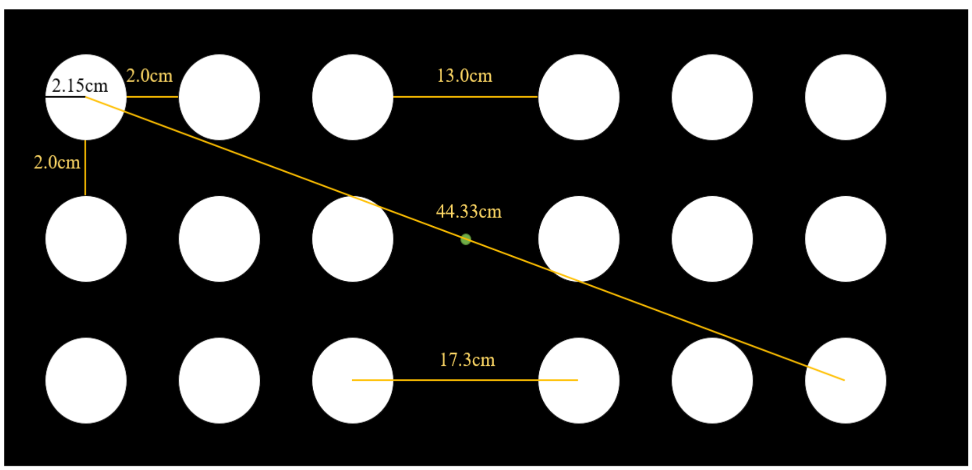

Figure 8: Size and distance of the placed circles

4.1.1 Quantitative Evaluation. Fig. 10 and Fig. 11 show the average success time for all participants and that for each participant, respectively. Fig. 10 shows that there is almost no difference in success time between OOW and FEI. Fig. 11 also shows that the number of participants who performed better with OOW than FEI was 6, and the number of participants who performed better with FEI was 5, almost half of the participants. There were no significant differences in these results.

For accuracy, the number of failures was 52 for OOW and 78 for FEI. The number of failures for the FEI was approximately 1.5 times to that for the OOW. This is thought to be due to the characteristics of OOW, which can accurately locate the circle, and the FEI, which can only locate the circle in the segmented area in the lost FoV. In addition, when the success time and the number of failures are considered together, the success time of the FEI is almost the same as that of the OOW, despite the fact that the number of failures of the FEI was larger. This can be considered that participants with FEI can respond quickly to events.

Success times and number of failures for each trial are also compared. The names of the locations where the circles appear are shown in Fig. 12. Table 1, Table 2 shows the time difference (s) between FEI and OOW for each trial regarding success time. Table 1 shows the results of task that moving the circle from L1 9 to R1 9, and Table 2 shows that from R1 9 to L1 9. Values shown in yellow indicates that OOW was faster than the FEI while those in green indicates the opposite. The symbols *, **, and *** indicate significance levels of 1%, 5%, and 10%, respectively. Table 1 shows that when moving the circle from the remaining FoV to the lost FoV Table 1, the OOW was faster than FEI in more trials (42/81). This may be due to that OOW can easily find the position of the yellow circle, which is the destination of the white circle, in the lost FoV, while for FEI, participants must judge where the white circle appears (in the remaining FoV or the location indicated by FEI in

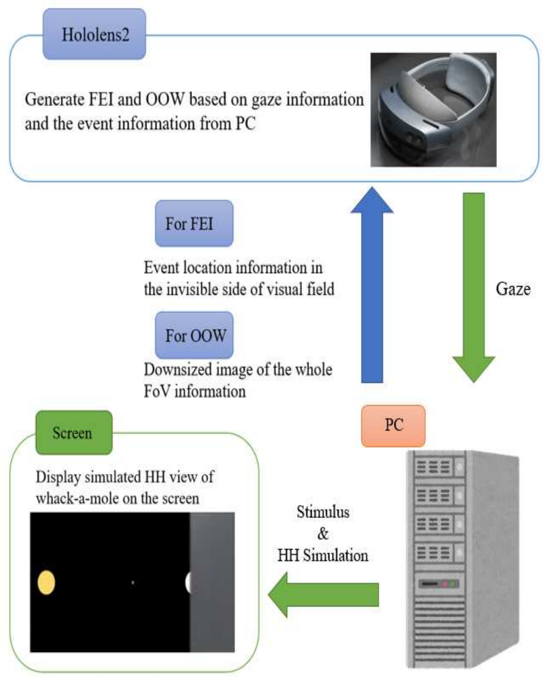

Figure 9: Flow of simulation of HH by eye tracking

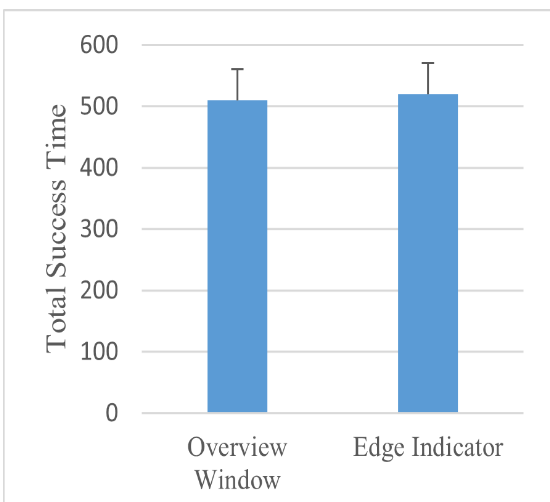

Figure 10: Average of all participants' success times

lost FoV) first. In addition, when moving the circle from the lost FoV to the remaining FoV Table 2, the FEI was faster than the OOW in more trials (42/81). This may be due to that it is easier for the FEI to quickly find information on the lost side. These results suggest that OOW is better for the task that related to move something from the remaining FoV to the lost FoV, while FEI is better for moving something from the lost FoV to the remaining FoV.

Table 1: Difference between FEI and OOW success times for each attempt Result of moving the circle from L1 9 to R1 9

	R1	R2	R3	R4	R5	R6	R7	R8	R9
L1	3.16	4.06	2.89	0.14	3.31	1.19	0.96	2.48	1.64
L2	3.17***	0.79	1.07	1.23	2.91**	0.82	1.44	0.43	3.46
L3	0.75	0.76	0.33	2.09***	1.63	0.91	4.96	1.81	0.01
L4	0.16	3.97	2.15	1.88	0.68	1.96	1.50	3.73	7.06
L5	0.38	3.37	0.24	3.05***	2.40	2.23	2.98	0.15	2.60
L6	1.44	0.10	1.28	1.98	0.08	0.23	2.04	0.91	0.45
L7	2.22	7.70**	2.69	2.30	5.62	2.19	5.90	0.01	1.42
L8	5.75***	2.02	2.95	0.55	0.33	0.30	2.94	1.56	1.31
L9	3.75	0.20	1.21	1.37	0.94	1.12	0.25	2.14	1.09

Table 2: Difference between FEI and OOW success times for each attempt Result of moving the circle from R1 9 to L1 9

	R1	R2	R3	R4	R5	R6	R7	R8	R9
L1	4.14	3.26	1.69	0.11	1.28	0.54	2.42	0.81	3.43
L2	0.43	0.19	1.18	0.07	0.75	3.70	0.10	1.69	1.5
L3	2.21	1.79	1.47	3.79	1.51	0.55	3.26	1.55	3.50
L4	0.30	2.11	5.56	2.4	2.82	1.74	0.05	2.04	0.11
L5	3.47	0.59	2.72	1.69	0.15	2.79	0.59	3.92	2.59
L6	1.09	0.40	0.88	2.73	0.61	2.88	2.43	0.02	0.51
L7	1.07	1.30	2.66	0.24	0.35	0.22	2.02	1.08	0.84
L8	6.20**	2.42	2.89	2.43	3.57	2.39	1.62	0.01	3.98
L9	2.32	0.47	2.54	0.75	4,39	0.57	0.13	2.67	1.02

4.1.2 Subjective Evaluation. Fig. 13 shows the RTLX results for the 6 indices. It shows that OOW was less burdensome on four indices (Intellectual and Perceptual Requirements, Physical Requirements, Time Pressure, and Frustration) and FEI was less burdensome on two indices (Job Performance and Effort). This may be attributed to the fact that the contextual task requires information from both the missing and the remaining part of FoV, and the OOW can see and confirm the information, so the burden was lower. However, because the OOW is always present in the FoV, it is necessary to make efforts to become accustomed to this situation. On the other hand, the FEI can find the circle instantaneously, so the participants felt that their performance was good. These results suggest that the best performance can be achieved by switching between OOW and FEI depending on the type of operation required.

5 CONCLUSION

In this paper, we designed and conducted the contextual task experiment to investigate the compensation effect for HH patients using OOW and FEI. The experimental result shows that FEI is more effective as an indicator for rapid response. On the other hand, we implemented an HH simulation scheme utilizing eye tracking for participants without visual field loss. The experimental result showed that it is necessary to switch between the FEI and OOW depending on the type of operation required.

As a future prospect, it is necessary to investigate how to judge various situations and switch between the FEI and OOW. In this study, we only studied that only 1 event happened in either side of visible and invisible. It is also necessary to investigate the situation that two or more events happened in invisible field.

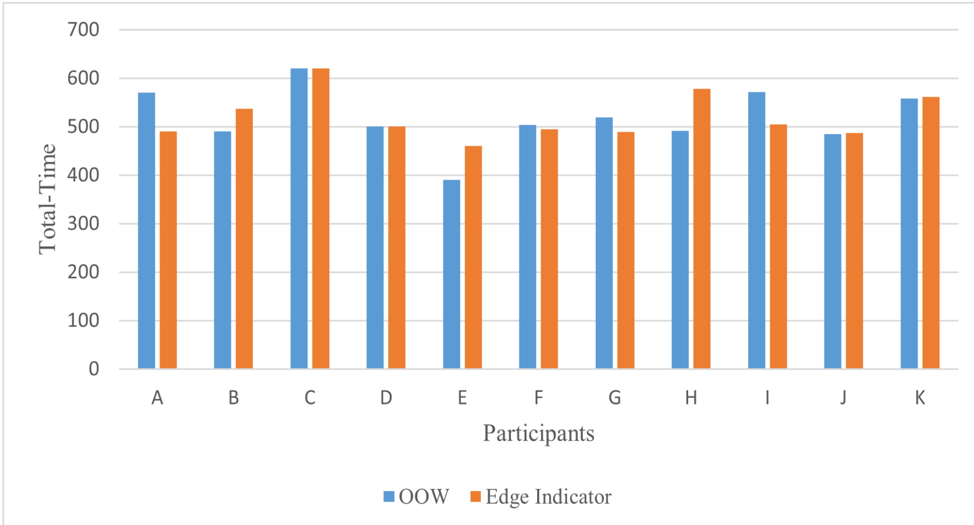

Figure 11: Success time per participant

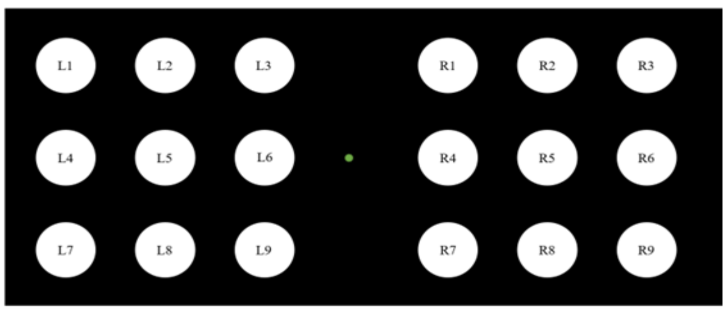

Figure 12: Name of the location where the circle will appear

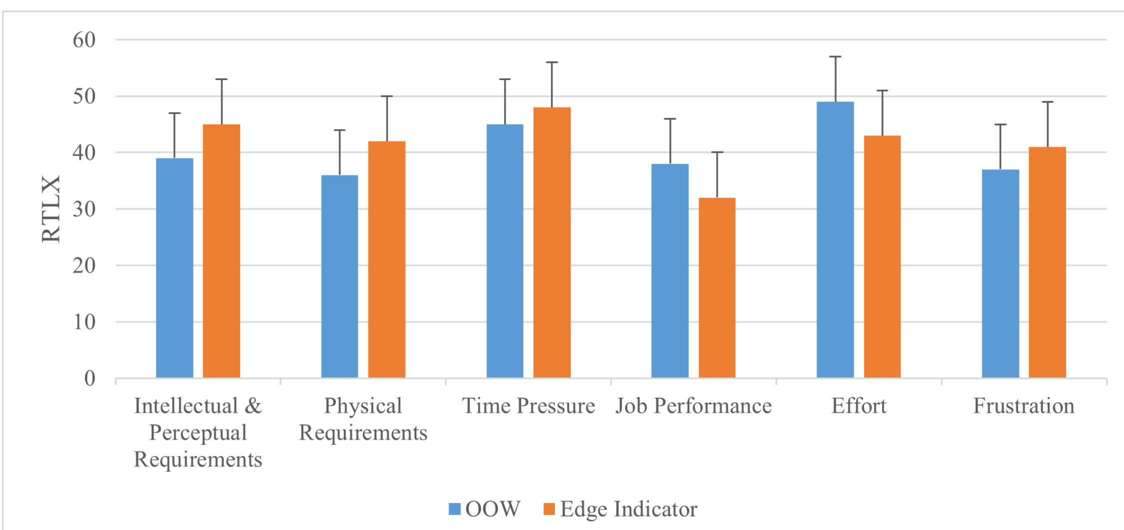

Figure 13: RTLX results for each of the six items in the contextual task

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