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Distribution of Attention in Augmented Reality: Comparison between Binocular and Monocular Presentation

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SUMMARY This study investigated the distribution of attention to frontal space in augmented reality (AR). We conducted two experiments to compare binocular and monocular observation when an AR image was presented. According to a previous study, when participants observed an AR image in monocular presentation, they perceived the AR image as more distant than in binocular vision. Therefore, we predicted that attention would need to be shifted between the AR image and the background in not the monocular observation but the binocular one. This would enable an observer to distribute his/her visual attention across a wider space in the monocular observation. In the experiments, participants performed two tasks concurrently to measure the size of the useful field of view (UFOV). One task was letter/number discrimination in which an AR image was presented in the central field of view (the central task). The other task was luminance change detection in which dots were presented in the peripheral field of view (the peripheral task). Depth difference existed between the AR image and the location of the peripheral task in Experiment 1 but not in Experiment 2. The results of Experiment 1 indicated that the UFOV became wider in the monocular observation than in the binocular observation. In Experiment 2, the size of the UFOV in the monocular observation was equivalent to that in the binocular observation. It becomes difficult for a participant to observe the stimuli on the background in the binocular observation when there is depth difference between the AR image and the background. These results indicate that the monocular presentation in AR is superior to binocular presentation, and even in the best condition for the binocular condition the monocular presentation is equivalent to the binocular presentation in terms of the UFOV.
key words: *augmented reality, monocular observation, useful field of view, visual attention, optical see-through*

1. Introduction

Rapid developments have recently taken place in technologies used in information presentation systems. One such system involves using augmented reality (AR) technology for information systems. AR is a technology for presenting artificial visual images in the real world. One of its most important advantages is that a user can simultaneously acquire information from the real world and superimposed artificial information. AR is presented to various modalities by using various methods, and it is expected to be useful for medical or traffic situations [1], [2]. In this paper, we refer to an optical see-through AR system. In this AR system, visual information is superimposed in the real world using a semi-transparent mirror. Actual car navigation systems employing AR are already being developed.

When using an AR system, a user can simultaneously obtain information from both the AR and the real world, while when using a conventional system, a user must alternate between the information display and the real world in front of the user [3]–[5]. This suggests that an AR system has an advantage over a conventional system in terms of driving safety. Nevertheless, even if a user does not have to move his/her eyes, attention may need to be shifted when there is a depth difference between AR image and the real space, leading to hazardous situations [6].

To address this problem, we have proposed an original system with monocular AR image presentation [4], [7], [8]. An AR image is perceived differently from a real image [9], [10], and distance perception in monocular AR image presentation is different from that in binocular AR presentation.

Kimura et al. [7] indicated that an observer perceived the distance from an AR image as greater when an AR image is monocularly rather than binocularly presented. In this experiment, there was difference in depth between the AR image and the background in the real space, and the AR image was presented nearer the participant than the background. In the monocular AR presentation, the AR image was perceived as if it were located on the background. This difference may influence the shift of visual attention.

We used the size of the useful field of view (UFOV) as an indicator of the available amount of visual attention. The UFOV means the area around the fixation point from which we can acquire information briefly [11]. The size of the UFOV varies depending on various factors. For example, when a task becomes more difficult and more attentional resources are required, the size of UFOV becomes narrower [3], [12], [13]. A previous study [14] found that using AR systems was effective for detection of hazardous situations, even if an observer's performance in a UFOV task was worse. However, this study investigated only the binocular AR presentation, so we examined the difference in the size of the UFOV between binocular and monocular AR presentations.

In the binocular AR presentation, perceived distances to the AR image and to the background are different. When

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we see the AR image and subsequently see the background, we have to move the focus of attention from the AR image to the background, even if we do not have to move the line of sight. This kind of attentional shift in depth itself requires attention [3], so the UFOV should be narrow. On the other hand, in the monocular AR presentation, the observer does not have to shift his/her attention because the AR image and the background are perceived to be the same distance away. The shift of attention in depth is not required. Thus the UFOV should be wider in the monocular AR presentation than in the binocular AR presentation. Degradation of the UFOV could lead to oversight or delay of response to an incident in the peripheral field of view.

Therefore, we predict that the available amount of visual attention may differ between the binocular observation and the monocular observation because of the difference in the perception of the distance.

The purpose of this study is to examine the effect of the shift of attention on the size of the UFOV in the binocular and monocular AR presentation. We conducted two experiments. In Experiment 1, there is depth difference between an AR image and the background. In this situation, the binocular AR condition is thought to have some disadvantages. In Experiment 2, there is no depth difference between an AR image and the background, and we used same task as in Experiment 1. In this situation, binocular AR presentation has no disadvantage.

2. Experiment 1

In Experiment 1, we examined whether the UFOV in the monocular AR presentation becomes wider than in the binocular AR presentation when there is depth difference between an AR image and the background.

2.1 Participants

Fourteen students of Osaka University took part in Experiment 1 (Male=7, Female=7). Their mean age was 21.1 (SD=0.9), and all had binocular normal or corrected-to-normal vision (at least 14/20). Before the experiment started, we informed all participants about the objectives of the experiment and tasks and then acquired their consent to participate.

2.2 Stimulus and Apparatus

Figure 1 shows the arrangement of apparatus. An AR image was presented on a liquid crystal display (LCD) and was reflected on a semi-transparent mirror. The LCD display was 50 cm from the semi-transparent mirror, and the semi-transparent mirror was 50 cm from the participants. Thus, the participants were 100 cm from the AR image. An AR image was presented on optically same distance in both the binocular and monocular AR conditions to examine the effect of differences in apparent distance on the size of the UFOV. The participants were 500 cm from the screen, so the AR image was 400 cm from the screen. This was the difference in depth. Because the objective of this experiment was to examine the characteristics of attention in a driving scenario, greater distance between the AR image and the background is ideal. Therefore, we positioned the apparatus to maximize the distance between the AR image and the screen. By using polarized filters, the AR image was presented as monocular or binocular.

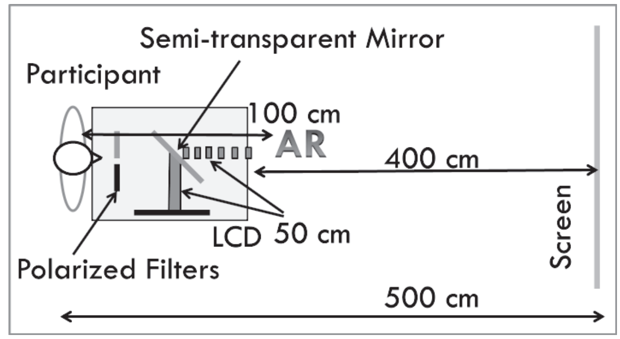

Fig. 1 Arrangement of apparatus for Experiment 1.

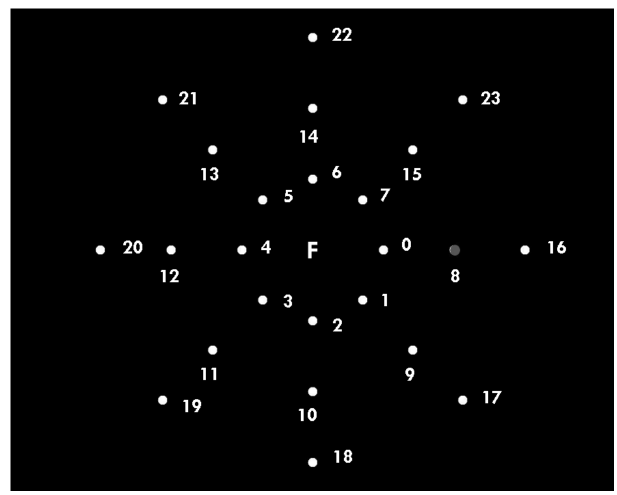

Fig. 2 Example of arrangement of task stimulus. In the central field of view, an alphanumeric character was presented. Numbers near dots were location ID numbers for the peripheral task. These numbers were actually not presented during the task. In this figure, luminance change occurs on No. 8.

Figure 2 shows the arrangement of the task stimuli. In the central field of view, an alphanumeric character was presented. It was used for the central task, and was 1.7° in visual angle squared. Luminance of stimulus was 7.3 cd/m^2 on the screen and 7.8 cd/m^2 for the AR image.

The size of stimulus for the peripheral task was 0.4° in visual angle. The distance of peripheral stimulus from the central task position was systematically manipulated. The dots were on three concentric circles, and a dot was allocated every 45° on each circle, meaning 24 dots in total. The diameters of the circles were 4.9° (near), 9.8° (medium) and 14.8° (far). Dots in the peripheral field of view were always presented on the background screen. Dots' luminance was 7.3 cd/m^2, and luminance of one dot may have changed to

1.6 cd/m^2 during the task. Change duration was 150 ms. If there was no interference, the luminance change could be detected and observed in the central field of view.

2.3 Procedure

In this experiment, a dual-task paradigm was used to measure the size of the UFOV. There were a central task and a peripheral task. The central task (letter/number discrimination) was presented in the central field of view. The peripheral task (luminance change detection) was presented in the peripheral field of view. Participants performed the central task as a main task and the peripheral task as a secondary task. The peripheral task was presented concurrently with the central task. Figure 3 shows the experimental procedure.

2.3.1 Central Task

There were three observation conditions for the central task as below.

1. Binocular Real: All stimuli presented on the background screen
2. Binocular AR: AR image presented binocularly
3. Monocular AR: AR image presented monocularly

First, the fixation point (+) was presented in the central field of view. Next, when a participant pressed keys, and after 500–1000 ms had passed, an alphanumeric character was presented instead of the fixation point. Then, participants determined whether the stimulus was a letter or number as quickly and accurately as they could and released the correct key. After participants responded to the central task, all stimuli were removed, and one trial of the central task was ended.

2.3.2 Peripheral Task

Stimuli for the peripheral task were presented around the stimulus for the central task as shown in Fig. 2. One of the dots was changed in luminance in half of all trials. Participants had to detect these changes. Luminance change started concurrently with the presentation of the central task. After 150 ms had passed, all stimuli for the peripheral task were removed. Even when luminance change did not occur, 150 ms after the presentation of the central task, all stimuli were removed. After participants responded to the central task, they orally answered whether a luminance change occurred or not.

2.3.3 Experimental Design

Observation conditions for the central task (3: Binocular Real · Binocular AR · Monocular AR) × Eccentricities of the peripheral task (3: near · medium · far) × the peripheral change positions (8: 8 directions) × the peripheral change (2: present / absent) × Repeat (10 times), total 1440 trials. This experiment was conducted for two days.

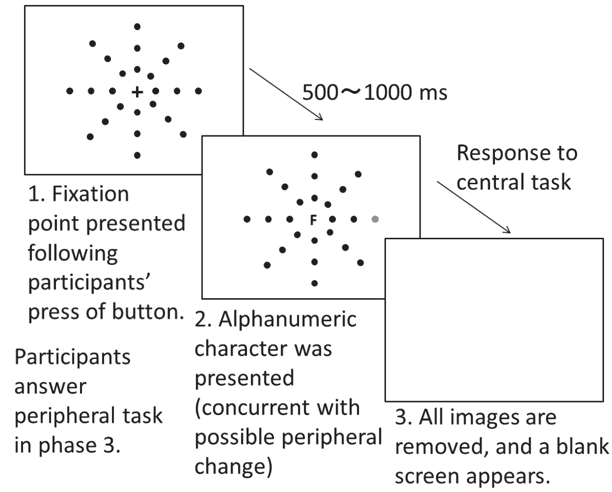

Fig. 3 Experimental procedure.

2.4 Hypothesis

For the binocular AR condition, participants must shift their attention from the AR image for the central task to the background screen for the peripheral task. This requires attentional resources; as a result, the UFOV would be narrower for the binocular AR condition than for both the monocular AR and binocular real conditions. In comparison, for the monocular AR and binocular real conditions, attentional resources would be saved, and the sizes of the UFOVs would be equivalent to each other and wider than in the binocular AR condition.

2.5 Results

Because of a high miss rate (defined as the proportion of peripheral luminance change that actually occurred that a participant did not detect) or false alarm rate (FA; defined as the proportion of peripheral luminance change that actually did not occur that a participant reported did occur), the data from three participants (Male=1, Female=2) were excluded. Therefore, 11 participants' data were analyzed.

2.5.1 Central Task

Response times for the central task were analyzed using a one-way (the observation condition for the central task) analysis of variance (ANOVA). There was no significant difference in the observation conditions (binocular real condition: 672 ms, binocular AR condition: 631 ms, monocular AR condition: 634 ms, $F(2, 20)=1.93$, *n.s.*).

Error rates for the central task were also analyzed using a one-way ANOVA. The main effect of observation condition was marginally significant (binocular real condition: 5.4%, binocular AR condition: 5.1%, monocular AR condition: 6.7%, $F(2, 20)=3.14$, $p < .10$) but according to Ryan's method, there was no significant difference between observation conditions (*n.s.*).

2.5.2 Peripheral Task

The error trials for the central task were discarded. Then, trials with response times under 100 ms or over 2000 ms for the central task were also discarded. Finally, response times beyond 2 standard deviations (±2SD) from the mean were considered outliers and excluded. The remaining trials (90.4% of all trials) were used for the analysis of the peripheral task. The hit rate (defined as the proportion of peripheral luminance change that actually occurred that a participant could detect) was analyzed using two-way (observation condition for the central task × eccentricities for the peripheral task) ANOVA. In this experiment, we did not ask participants to report the location at which they perceived the luminance change when a FA was reported. Thus, FA rate and d′ (sensitivity measure defined by hit rate and FA rate) could not be calculated for each dot location. For the analysis of the peripheral task, we used hit rate instead of d′. As a result, the main effects of observation condition for the central task ($F(2, 20)=4.19$, $p<.05$), eccentricities of the peripheral task ($F(2, 20)=8.60$, $p<.005$), and the interaction of the two factors ($F(4, 40)=2.97$, $p<.05$) were all significant. Figure 4 shows areas with a hit rate over 70%. The analysis of the simple main effect (observation condition for the central task × eccentricities of the peripheral task) showed the simple main effect of observation condition was significant in the near eccentricity ($F(4, 40)=7.20$, $p<.005$). According to Ryan's method, the monocular AR condition and the binocular real condition had significantly higher hit rates than the binocular AR condition in the near eccentricity ($p<.05$).

The simple main effects of the eccentricity were significant in all observation conditions. In the binocular real and monocular AR conditions, hit rates in the near and medium eccentricities were higher than in the far eccentricity ($p<.05$). In the binocular AR condition, the hit rate in the medium eccentricity was higher than in the far eccentricity ($p<.05$).

The hit rates in each eccentricity were analyzed using a two-way ANOVA (observation condition for the central task × dot location). As a result, the main effects of the observation condition for the central task ($F(2, 20) = 5.75$, $p < .05$), the dot location ($F(7, 70) =3.84$, $p<.005$) and the interaction of the two factors ($F(14, 140)=7.23$, $p<.001$) were all significant in the near eccentricity (see Fig. 2, dots 0–7). Figure 5 shows hit rates in each observation condition in the near eccentricity. In the binocular AR condition, the simple main effect of dot location was significant ($F(7, 210)=14.67$, $p<.001$). According to Ryan's method, at dots 0 and 1, hit rates were lower than in the other locations ($p<.05$). In the binocular real and monocular AR conditions, hit rates did not degrade at dots 0 and 1.

In the far eccentricity (dots 16–23), the main effect of eccentricity was significant ($F(7, 70)=3.46$, $p<.005$), and the main effect of the observation condition was marginally significant ($F(2, 20)=3.05$, $p<.10$). The interaction of the two factors was significant ($F(14, 140)=2.12$, $p<.05$).

Figure 6 shows hit rates in each observation condition in the far eccentricity. The analysis of the simple main effect (observation condition × dot location) showed the simple main effect of observation condition was significant in dots 17, 21, and 22 ($F(2, 160)=3.58$, $p < .05$, $F(2, 160)=4.37$, $p<.05$, $F(2, 160)=6.31$, $p<.005$, respectively).

According to Ryan's method, at dot 17, the monocular AR condition had a higher hit rate than the binocular AR condition ($p<.05$). At dots 21 and 22, the monocular AR condition had a higher hit rate than the binocular real and binocular AR conditions ($p<.05$).

In the medium eccentricity, neither the main effects of

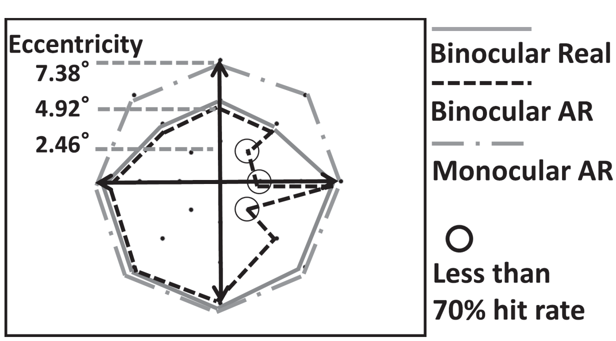

Fig. 4 Hit rates higher than 70% in Experiment 1. Circles in the binocular AR condition indicate hit rates were less than 70%, but lines are connected because these dots are the most internal dots.

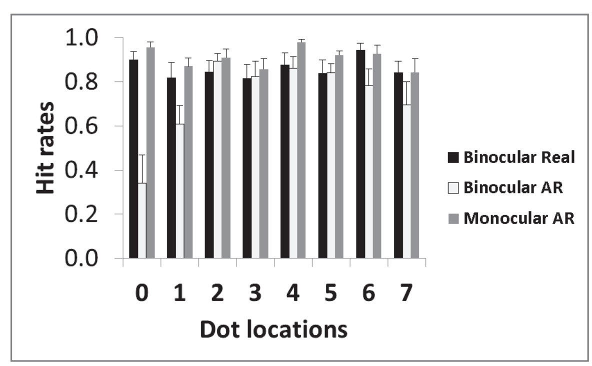

Fig. 5 Hit rates in each observation condition in the near eccentricity. Error bar indicates standard error.

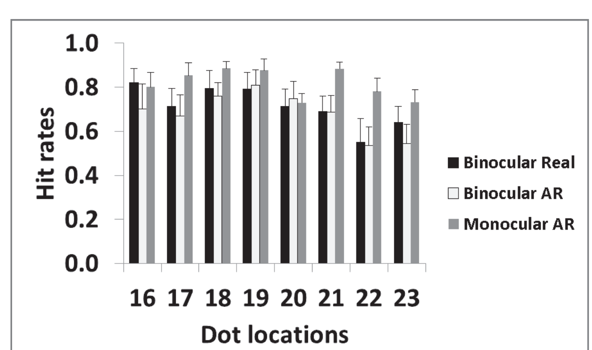

Fig. 6 Hit rates in each observation condition in the far eccentricity. Error bar indicates standard error.

the observation condition for the central task, dot location nor the interaction of the two factors was significant (*n.s.*).

2.6 Discussion

The results of the near and far eccentricities support the hypothesis that the UFOV in the monocular AR condition would be wider than in the binocular AR condition. On the other hand, the hit rates in the monocular AR and binocular real conditions do not support the hypothesis that the UFOV in the monocular AR condition would be equivalent to the binocular real condition. This is because hit rates in the upper area in the monocular AR condition were superior to those in the binocular real condition.

The monocular AR condition could be considered superior to the binocular AR condition because of the shift of attention. However, although in the binocular real condition the shift of attention was not required, the monocular AR condition was superior to the binocular real condition. Previous studies examining the characteristics of the upper and lower visual field have indicated that visual detection performance is better in the lower visual field [15], [16], and that performance decrement in the far eccentricity was greater in the upper visual field [16]. This suggests that visual attention operates more effectively in the lower field than in the upper field. Our finding that hit rates in the binocular real and binocular AR condition were lower in the upper field is consistent with these findings.

In the binocular AR condition, hit rates significantly degraded in particular areas. This is because in Experiment 1, an AR image was presented in the center of the concentric circles for the peripheral task when a participant observes stimuli with the dominant eye. Because most participants' dominant eye was the right one, the AR image observed with the left eye was located on the right of the center of the circles. In addition, the stimulus changed in luminance concurrently with the stimulus presented in the central task, so the stimulus presentation in the central task possibly prevented the luminance change detection in the peripheral task at dots 0 and 1.

An AR image was presented nearer a participant than the background screen, and the participant performed the central task as the main task. Thus, the stimuli for the peripheral task were perceived as "double vision" in the binocular AR condition, in which the depth difference between AR image and the background was perceived. However, the double vision problem never occurred in the binocular real and monocular AR conditions, in which depth difference was not perceived. It is considered that in the monocular observation, an observer cannot use binocular depth cues like convergence and so does not perceive depth difference. Thus, participants had more difficulty detecting the stimuli for the peripheral task in the binocular AR condition than in the binocular real and monocular AR conditions.

3. Experiment 2

In Experiment 1, it is indicated that when no depth difference exists between the AR image and the background, the UFOV in the monocular AR condition was wider than in the binocular AR condition.

In the monocular AR condition, the perceived AR image location and the background location are equivalent, which leads to the superiority of the size of the UFOV in the monocular AR condition. If no depth difference exists between AR image and the background, it is supposed that this superiority of the monocular AR condition will not remain. Moreover, in this situation, the binocular AR condition may have an advantage over the monocular AR condition because the stimulus presented to each eye is different.

In Experiment 2, there was no depth difference between an AR image and the stimuli for the peripheral task, and both were presented near a participant. The objective of Experiment 2 was to examine whether the monocular AR condition is inferior to the binocular AR condition when the binocular AR condition has no disadvantages.

3.1 Participants, Stimulus and Appratus

Ten students took part in Experiment 2 (Male=7, Female=3). Their mean age was 21.3 (SD=1.2), and all had binocular normal or corrected-to-normal vision (at least 14/20). Before the experiment started, we informed all participants about objectives of the experiment and tasks and then acquired their consent to participate.

3.2 Stimulus and Appratus

Figure 7 shows the arrangement of apparatus. The CRT monitor replaced the screen used in Experiment 1 and was used to present stimuli of the peripheral task and the central task in the binocular real condition. The CRT monitor and the AR image were both 50 cm from the participants. To adjust task difficulty, the diameters of concentric circles were doubled.

3.3 Procedure

The experimental procedure was same as in Experiment 1, and the dual tasks were the central task and the peripheral task.

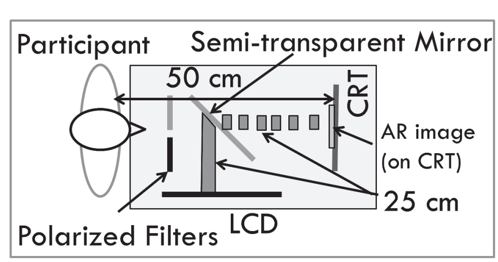

Fig. 7 Arrangement of apparatus for Experiment 2.

3.4 Results

Because of a high miss rate and a high false alarm rate, the data from two participants (Male=1, Female=1) were excluded. Therefore, eight participants' data were analyzed.

3.4.1 Central task

Response times for the central task were analyzed using a one-way (observation condition for the central task) ANOVA. There was a marginally significant difference in the observation conditions (binocular real condition: 571 ms, binocular AR condition: 585 ms, monocular AR condition: 603 ms, $F(2, 14)=3.34$, $p<.10$). In accordance with Ryan's method, the response time of the monocular AR condition was marginally longer than the binocular real condition ($p<.10$). There was no significant difference between the binocular AR condition and the monocular AR condition (*n.s.*). Error rates were also analyzed in the same manner as in Experiment 1. There was no significant difference between observation conditions (*n.s.*).

3.4.2 Peripheral task

Trials were filtered in the same manner as in Experiment 1 (89.3% of all trials). The hit rate was analyzed using two-way ANOVA (observation condition for the central task × eccentricities of the peripheral task). As a result, the main effect of eccentricities of the peripheral task ($F(2, 14)=4.25$, $p<.05$) was significant. The main effect of observation condition for the central task and the interaction of the two factors were not significant ($F(2, 14)=1.00$, *n.s.*; $F(4, 28)=0.80$, *n.s.*, respectively). In accordance with Ryan's method, hit rates were marginally higher in the near and medium eccentricities than in the far eccentricity ($p<.10$).

The hit rates in each eccentricity were analyzed using a two-way ANOVA (observation condition for the central task × dot location) as in Experiment 1. As a result, the main effect of the observation condition, neither the main effect of dot location nor the interaction of two factors were significant (*n.s.*). Figures 8 and 9 show hit rates of each observation condition and each dot location in the near and far eccentricities. Moreover, in the far eccentricity, there was no significant difference in the observation condition. This indicates the sizes of the UFOVs were similar in all the observation conditions.

3.5 Disccusion

The results of the central task in Experiment 2 indicate that there was marginally significant difference between the monocular AR condition and the binocular real image conditions. However, there was no significant difference between the monocular AR condition and the binocular AR condition. This does not indicate that the monocular AR condition has a disadvantage compared with the binocular AR condition.

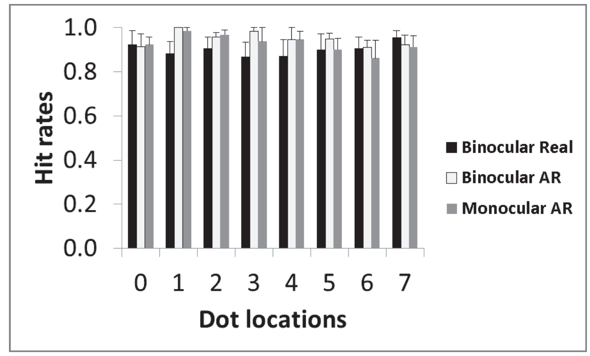

Fig. 8 Hit rates in each observation condition in the near eccentricity. Error bar indicates standard error.

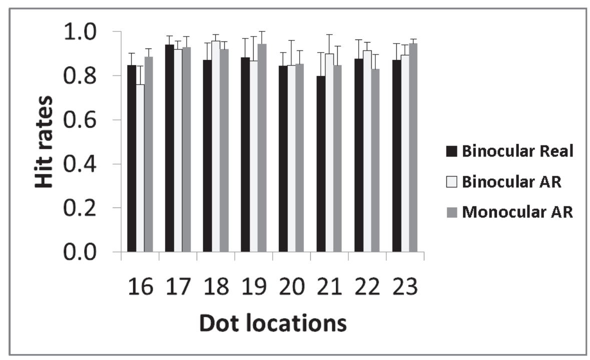

Fig. 9 Hit rates in each observation condition in the far eccentricity. Error bar indicates standard error.

In Experiment 2, the distance of the central task and the peripheral task was same, the shift of attention was not required in all conditions. And because the double vision problem did not occur in binocular AR condition, hit rates in the near eccentricity did not degenerate like in Experiment 1. In the situation in which the binocular AR condition does not have any disadvantage, the UFOV in the monocular AR condition is essentially equivalent to the binocular AR condition. Therefore, these results indicate that in the monocular AR condition the observer can acquire information from the central field of view and also the peripheral field of view, equivalent to the binocular AR condition. And the UFOV in the monocular AR presentation does not have disadvantages.

4. General Discussion

In this study, we examined advantages of the monocular AR presentation systems by using UFOV tasks. In Experiment 1, in which depth difference existed between an AR image and the background, the size of the UFOV in the monocular AR condition became wider than that in the binocular AR condition. This supported the hypothesis that more attentional resources are available to the peripheral field of view in the monocular AR condition than in the binocular AR condition.

An alternative hypothesis with regard to why the monocular AR was superior in terms of UFOV might be that, in the monocular AR condition, the AR image was not presented to the non-dominant eye. This could enable the participant to distribute more visual attention to the peripheral field of view. According to this alternative explanation, it was interpreted that visual attention of the non-dominant eye in the monocular AR condition was not required to perform the central task, and that the participant could deploy residual visual attention to the peripheral area of visual field of the non-dominant eye, resulting in the wider UFOV observed in the monocular AR condition. Based on this hypothesis, it is expected that the monocular AR condition should be superior to both the binocular real and binocular AR condition in Experiment 2 as well, as there was no difference in distance perception among observation conditions. However, dominance in the monocular AR condition was not observed, and thus, the difference in depth distance is thought to be the key.

However, in Experiment 1, the monocular AR was superior to the binocular real condition, in which the shift of attention was not required. This result indicates the monocular AR presentation has additional advantages for the UFOV aside from those pertaining to depth perception. We have not yet identified this factor, and thus, more precise research must be conducted.

A previous study [14] revealed the relationship between the UFOV and hazardous situation detection when using AR. No matter if an observer had wide UFOV or not, AR systems were useful for detecting hazardous situations in the binocular vision. We revealed the shift of visual attention in the monocular presentation was different from that in the binocular presentation.

In the binocular AR condition, the hit rates decreased in the right-side near area. An AR image presented to the non-dominant eye may prevent observation of the change in luminance in the peripheral task on the background (see Figure 10 for details). In Experiment 1, the dominant eye could observe an AR image on the center of a concentric circle of the peripheral task. On the other hand, the non-dominant eye observed the AR image slightly depart from the center of the concentric circles. This can inhibit the detection of luminance change on the background. In the situation in which the spatial location of the AR image must be recognized separately, the binocular AR presentation in which depth cues are available is necessary. However, in the driving situation in particular, the AR image need not be recognized as spatially separate from the background. Furthermore, a wide UFOV is highly desirable for detecting traffic hazards. Thus, the monocular AR presentation, which enables the UFOV on the background to be wider, is very suitable for an in-vehicle visual user interface.

Difference in depth causes some disadvantages such as the double vision problem and the use of additional requirements to shift attention. In Experiment 2, the AR image and the background are manipulated to appear the same distance away. Thus, neither the double vision problem nor the shift of attention in depth occurred. The results of this experiment show that participants perform two tasks equivalently in the monocular and binocular AR conditions. This indicates that the monocular AR presentation is as useful as the binocular AR presentation even if it seems to be an unnatural method of visual observation.

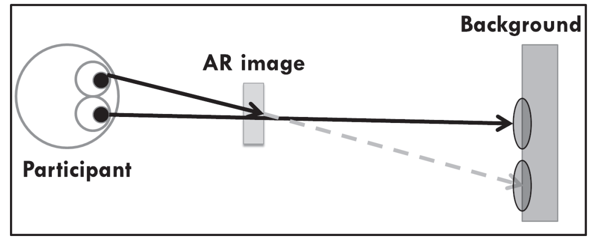

Fig. 10 Example of location of AR image in the binocular AR condition. When the right eye is dominant. In Experiment 1, seen with the dominant eye, an AR image was presented in the center of concentric circles and then seen with the non-dominant eye, the image located was on the right of the center of the peripheral task.

5. Conclusion

This study described how monocular AR observation is superior to binocular AR observation in terms of the UFOV. When there is depth difference between AR image and the background in the real space, the UFOV becomes wider in the monocular AR condition than in the binocular AR condition. Even when the negative factors for the binocular AR were removed, the UFOV in the monocular condition was equivalent to that in the binocular condition. In short, the monocular AR presentation is advantageous for the visual presentation method of an AR user interface.

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