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Attention shift not memory averaging reduces foveal bias

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Abstract

Two experiments examined which of two mechanisms, attention shift or memory averaging, reduces foveal bias. The target stimulus was a black dot presented for 80 ms while observers maintained fixation. The two main conditions were 'with' and 'without' vertical and horizontal bars as landmarks, which were placed on more eccentric positions than the target stimulus. To induce attention, the landmark was flashed on for 80 ms (Experiment 1) or disappeared (Experiment 2) with a stimulus onset asynchrony of 0, 106.4, or 212.8 ms in both experiments. As a control, non-flashed and non-disappeared landmark conditions were employed. The observers' task was to point to the remembered location of the target with a mouse cursor. The results showed that the magnitudes of foveal bias were significantly lower in the flashed and disappeared landmark conditions than in the without landmark condition. Furthermore, the magnitudes in the flashed and disappeared landmark conditions did not differ from their respective control conditions. The latter finding in the disappeared landmark conditions provides evidence for 'attention shift' against 'memory averaging' as the mechanism reducing foveal bias.

Keywords: Attention shift; Memory averaging; Foveal bias; Landmark

1. Introduction

A phenomenon that has drawn much attention in vision science is foveal bias. It refers to the distortion of location memory in which an object transiently presented in the retinal periphery is reproduced closer to the retinal center, i.e., the fovea (Mateeff & Gourevich, 1983, 1984). It was reported that foveal bias occurred regardless of the presence or absence of an actual fixation point (Van der Heijden, van der Geest, de Leeuw, Krikke, & Musseler, 1999). This implies that the fixation point served merely as a cue for fixation and not as a visual landmark (Sheth & Shimojo, 2001) suggesting that foveal bias might not result from *memory averaging*[1] between the fixation point and the target. It has been also reported that the frequency of foveal bias decreased in the presence of an additional display element (Sheth & Shimojo, 2001).

A question naturally arises as to how an additional element reduces foveal bias. One possible mechanism for reduction might be memory averaging. Hubbard and Ruppel (2000) reported that memory of a target

[1] When two adjacent objects are to be memorized, each location of the two objects is associated. During association in memory, spatial averaging of the positions of the two objects takes place. Consequently, two objects may be reproduced towards each other. We call this localization bias 'memory averaging'. Memory averaging predicts that the position of a briefly presented target will be associated with one of the permanently visible landmarks, resulting in the localization bias of the target towards it.

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was displaced towards a landmark/distracter; a distortion they referred to as 'landmark attraction' or more generally as 'memory averaging'. However, Kerzel (2002b) reported that memory averaging between a peripheral target and neighboring distracter did not occur. Rather, the target was reproduced away from the distracter (see also Werner & Diedrichsen, 2002). Thus, reproduced locations do not appear to be consistently biased towards the distracter. Therefore, we can neither accept nor refute memory averaging as an underlying mechanism for the reduction of foveal bias.

An alternative mechanism for the reduction of foveal bias might be the attention shift towards the distracter. Kerzel (2002a) showed that the reproduced location of a moving target was displaced towards a distracter abruptly appearing at the time of target disappearance or thereafter. He suggested that an attention shift towards a transient distracter might underlie the attraction of the memory for location of the target towards the distracter. However, the contributions of attention shift and memory averaging were not segregated in his experiments. Moreover, the target stimulus in his experiments was a moving one. The memory for the final position of a moving target is displaced forward in the direction of its motion trajectory which is not the case with a stationary target. Therefore, it is unsure whether the same suggestion of attention shift (or memory averaging) modifying the localization performance could be extended to a stationary target as well.

From the above review, it appears inconclusive which of two mechanisms, attention shift towards an additional element or memory averaging of the target and the additional element, reduces foveal bias. Therefore, it is relevant to address this issue in the present study by examining whether spatially cueing a landmark near a target would reduce the magnitude of foveal bias. In Experiment 1, the landmark nearest the target was flashed on with a variable stimulus onset asynchrony (SOA). In Experiment 2, the landmark was suddenly vanished with the same variable SOA as in Experiment 1. The results provide supporting evidence for attention shift against memory averaging as an underlying mechanism reducing foveal bias.

2. Experiment 1

We examined whether or not a shift of visual attention towards the landmark reduces foveal bias by comparing responses in three experimental conditions: with or without flashed landmarks, and without a landmark. We expected that landmark conditions (flashed and non-flashed) would yield lower foveal bias than without landmark conditions. We further expected that the flashed conditions would result in lower foveal bias than non-flashed conditions.

2.1. Methods

2.1.1. Participants

Nine graduate psychology students (ST, YT, TS, YY, YM, DK, RI, NN, and SH; 4 females and 5 males) of Kyushu University volunteered as observers. They were aged between 23 and 28 years with a mean age of 26 years and all had normal or corrected-to-normal vision. All observers were extensively experienced in psychophysical experiments; however, they all were naive of the purpose of the experiment.

2.1.2. Apparatus and stimuli

The stimuli were programmed in Delphi 6 with DirectX and displayed on a 19-in. color CRT monitor (Nanao, Flex Scan T761) with a pixel resolution of 1024×768 and refresh rate of 75 Hz. A Sony Video Audio Integrated Operation (VAIO) PC interfaced with the monitor and controlled stimuli presentation and data collection. The target was a black dot (luminance 10 cd/m^2) of 0.33° in diameter and the landmarks were four identical bars (luminance 10 cd/m^2) 2° in length and 0.2° in width. Landmarks were 12° eccentric and placed to the left, right, top, and bottom to avoid predictability of the target location. Left and right bars, and top and bottom bars were vertically and horizontally aligned with the fixation mark, respectively. The fixation mark (luminance 1.32 cd/m^2) subtended 1° in length and 0.04° in width and was centered on the screen. The background was black (luminance 0.1 cd/m^2). The target was presented randomly at an eccentricity of 3°, 6°, or 9° from the fixation mark at one of four predetermined directions 0°, 90°, 180°, and 270° in polar angle, where 0° was used to represent the right horizontal direction from which the values increased counterclockwise. The two main experimental conditions were 'with' and 'without' a landmark. The 'with landmark' condition was manipulated in two ways by causing the landmark to flash and not flash. In the flashing condition, the landmark was flashed (100 cd/m^2) on for about 80 ms with a SOA of 0, 106.4, or 212.8 ms. Thus, a total of five experimental conditions were included in this experiment which followed a two factor, within group design. The basic paradigm of the experiment is schematized in Fig. 1.

2.1.3. Procedure

The experiment was conducted in a darkened room and the observers viewed the display binocularly. Observers sat 50 cm away from the CRT display. A chin-and-head rest was used to stabilize their visual field and to match their eye level to that of the fixation mark. The experiment was self-paced; observers initiated each trial by pressing the space key while maintaining fixation on the fixation mark. Fifty milliseconds later a target appeared for 80 ms, during which time observers were required to continue maintaining fixation while memo-

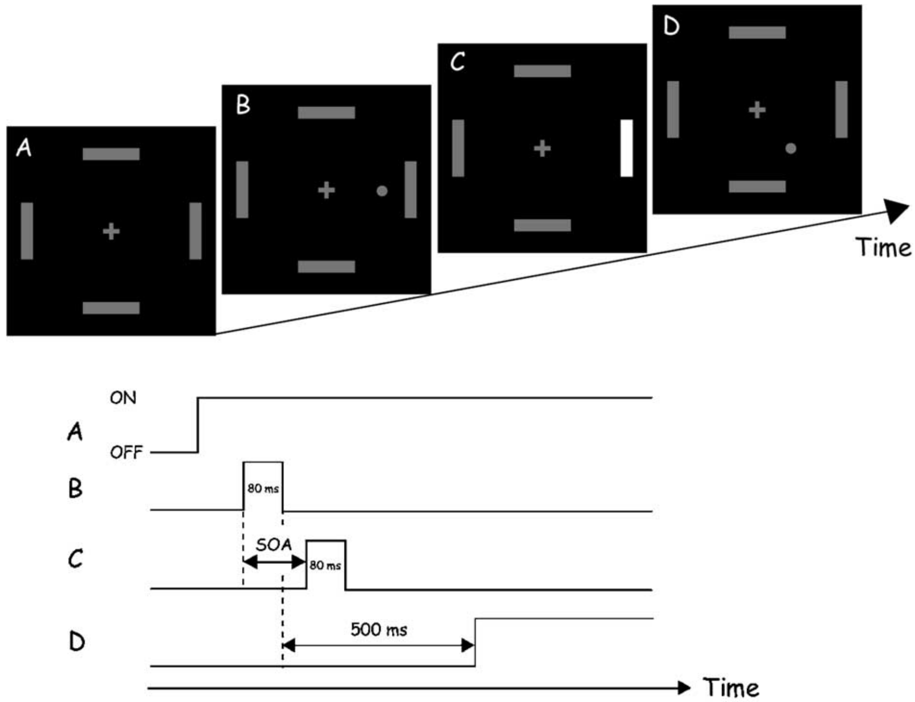

Fig. 1. Schematic representation of the experimental protocol. (A) Four bars serving as landmarks were presented. (B) A target (dot) appeared 50 ms after the space key was pressed. (C) The landmark nearest the target was flashed for 80 ms (Experiment 1), or made to disappear until a response was given (Experiment 2). (D) The mouse cursor appeared 500 ms after target offset.

rizing the location of the target. Observers were instructed to continue maintaining fixation until a mouse cursor appeared. After a retention interval of 500 ms following target offset, the mouse cursor identical to the target in all respects appeared at a random location within an imaginary square of 4° sides concentric with the center of the target. The observers' task was to position the cursor on the remembered location of the target then to press the left button of the mouse to record the screen coordinates. During localization, eye movements were allowed. After pressing the mouse button, the trial was terminated and observers were asked to refix their gaze for the following trial. Observers received six blocks of 48 trials each in a single session lasting about 30 min including breaks between blocks. The first five blocks each consisted of randomly intermixed conditions of four 'with landmark' conditions and the last one only of the 'without landmark' condition. The first block was regarded as practice and was disregarded in the statistical analysis. Thus, each observer performed a total of 240 experimental trials (5 experimental conditions × 3 target eccentricities × 4 target directions × 4 repetitions).

3. Results and discussion

3.1. Basic data

The x and y coordinates of the target presented on the horizontal and vertical axes, respectively, were subtracted from the corresponding coordinates of the respective responses to obtain the magnitudes of the displacements. Positive and negative values are indicative of landmark and foveal bias, respectively. Displacements for each eccentricity were averaged over four target directions and four repetitions to obtain the mean displacement per condition per observer. The mean displacements thus obtained constituted the basic data for the analysis. Thus, a total of 135 (5 experimental conditions × 3 target eccentricities × 9 observers) basic data were available for further analyses.

Mean displacements as a function of experimental condition and target eccentricity are plotted in Fig. 2. An ANOVA showed a significant main effect of experimental condition ($F(4,32) = 3.21$, $p < .05$) and an interaction effect ($F(8,64) = 2.54$, $p < .05$). Post-hoc tests (Ryan's method) for the pair-wise comparisons of the main effect showed significantly lower foveal bias in the 'flashed landmark' condition with a SOA of 106.4 ms than in the 'without landmark' condition. Post-hoc tests for the simple main effect of the interaction between experimental condition and target eccentricity showed that foveal bias in the 'with landmark' conditions (flashed and non-flashed) were significantly lower than in the 'without landmark' condition at 9° target eccentricity. An ANOVA for flashed landmark conditions showed significant ($F(2,16) = 3.919$, $p < .05$) main effect of SOA; with the lowest foveal bias corresponding to 106.4 ms, followed by another with 212.8 ms and the highest foveal bias corresponding to 0 ms SOA.

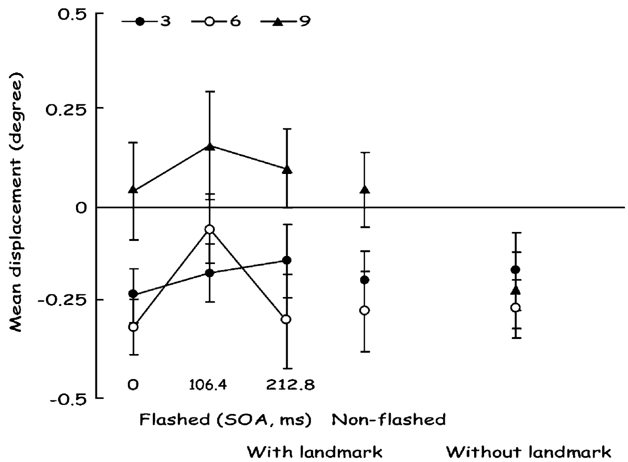

Fig. 2. Mean displacements plotted as a function of five experimental conditions: 'with landmark' (flashed with SOAs of 0, 106.4, and 212.8 ms, and 'non-flashed') and 'without landmark' conditions and three target eccentricities (3: filled circle, 6: open circle and 9: triangle). Each data point was obtained by averaging 144 measurements (4 target directions × 4 repetitions × 9 observers). Vertical bars denote one standard error of the mean among observers.

The above results are in agreement with the expectation that landmark conditions (flashed and non-flashed) would result in lower foveal bias than without landmark conditions. However, they are not in agreement with the expectation that flashed conditions would result in lower foveal bias than non-flashed condition. In fact, the magnitude of foveal bias in the flashed conditions was smaller but not statistically different from that in the non-flashed condition. This signifies that the mere presence of a landmark drew attention as did the flashed landmark and reduced foveal bias; however, the flash added an insignificant magnitude of reduction. The results also showed that the effect of landmark was largest when target was presented closest to it. The results seem to suggest that the distracter can affect foveal bias within a certain spatial range. Moreover, the SOA showing significant reduction of foveal bias was congruent with that causing large cueing effects in the cost-benefit paradigm (Posner, 1980).

The above results unequivocally suggest that landmark biases localization towards it. However, at this stage our objective to identify which of attention shift and memory averaging was critical in biasing localization towards landmark is not achieved. A critical drawback to this experimental paradigm was the visibility of landmark in both flashed and non-flashed conditions after the target had disappeared. Accordingly, we cannot argue for the possibility that attention shift to the landmark itself induced spatial shift that was purely the source of the reduction nor can we argue for the alternative that the position of landmark was spatially 'averaged' with the target in memory.

To resolve the above issue we employed in the next experiment a new sequence of stimuli in which the landmark nearest the target was suddenly caused to disappear. By examining this condition, we tried to provide evidence for/against attention shift or memory averaging reducing foveal bias. We expected that both disappeared and non-disappeared conditions would yield lower foveal bias than without landmark conditions while the former conditions would not differ from themselves if attention shift account was valid. On the other hand, non-disappeared conditions would yield lower foveal bias than both disappeared and without landmark conditions while the latter conditions would not differ from themselves if memory averaging account was valid.

4. Experiment 2

4.1. Methods

4.1.1. Participants

Nine graduate psychology students (ST, TS, HS, SS, MI, SR, KS, DK, and AY; six females and three males) of Kyushu University volunteered as observers. ST, TS, and DK also participated in Experiment 1. The participants' ages ranged from 21 to 28 years with a mean age of 26 years, and all had normal or corrected-to-normal vision. All were extensively experienced in psychophysical experiments; however, they were naive of the purpose of the experiment.

4.1.2. Experimental conditions

The experimental conditions were identical to those in Experiment 1 except for the following: the landmark was made to disappear with the three SOAs used in the 'flashed landmark' conditions.

4.1.3. Apparatus and stimuli

The stimuli were identical to those used in Experiment 1 except for the following: the luminance of the fixation mark, landmark, and target was 1.32 cd/m^2 while that of the background was 19 cd/m^2.

4.1.4. Procedure

All procedures were identical to Experiment 1.

4.2. Results and discussion

Mean displacements as a function of experimental condition and target eccentricity are plotted in Fig. 3. An ANOVA revealed significant main effects of experimental condition ($F(4,32) = 6.203$, $p < .01$) and target eccentricity ($F(2,16) = 11.547$, $p < .015$). Post-hoc pairwise comparisons (Ryan's method) of the main effect of experimental condition showed that foveal bias in the 'disappeared landmark' conditions with a SOA of 106.4 and 212.8 ms was significantly lower than in the 'without landmark' condition. Pair-wise comparisons

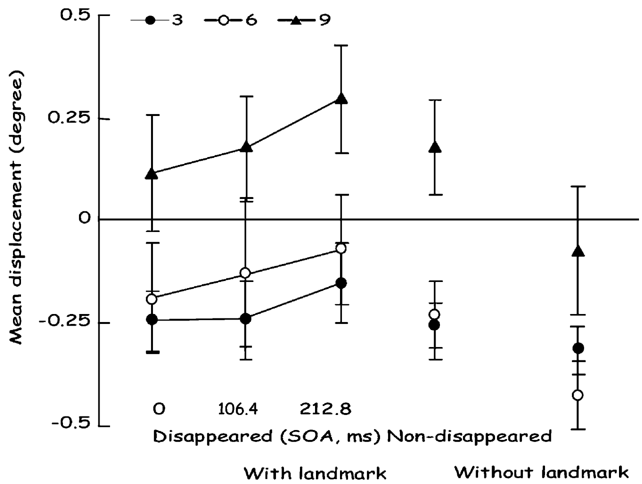

Fig. 3. Mean displacements plotted as a function of five experimental conditions: 'with landmark' ('disappeared' with SOAs of 0, 106.4 and 212.8 ms, and 'non-disappeared') and 'without landmark' conditions and three target eccentricities (3: filled circle, 6: open circle, and 9: triangle). Each data point was obtained by averaging 144 measurements (4 target directions × 4 repetitions × 9 observers). Vertical bars denote one standard error of the mean among observers.

of the main effect of eccentricity showed a significantly lower foveal bias for targets at 9° eccentricity than those at 3° and 6°. An ANOVA for disappeared landmark conditions showed significant main effect of eccentricity ($F(2,16) = 9.204$, $p < .01$) and non-significant main effect of SOA ($F(2,16) = 3.320$, $p > .05$). Following the non-significant SOA effect, we collapsed the data across all disappeared conditions and ran a two-way [3 (mean of disappeared, non-disappeared, and no-landmark) × 3 (3, 6, 9 degree of eccentricity)] repeated measures ANOVA, which yielded significant main effects of experimental condition ($F(2,16) = 9.089$, $p < .005$) and target eccentricity ($F(2,16) = 12.311$, $p < .001$). Pair-wise comparisons showed that disappeared conditions did not differ significantly from non-disappeared condition whereas they both differ significantly from without landmark condition ($t_{16} = 4.102$, $p < .001$; $t_{16} = 3.057$, $p < .001$, respectively).

The above results clearly show that 'attention shift' was the crucial factor that reduced foveal bias. As in Experiment 1, foveal bias was significantly reduced when the SOA was 106.4 and additionally when 212.8 ms. In the disappeared landmark conditions, the landmark was no longer available after the disappearance. Therefore, we cannot attribute the significant reduction of foveal bias observed in the disappeared conditions to memory averaging of the target and attended landmark. In addition, both disappeared and non-disappeared conditions differed significantly from without landmark condition in this experiment. This latter finding suggests that the common mechanism in disappeared and non-disappeared conditions was attention shift that biased localization towards the landmark, thus reducing the foveal bias.

5. General discussion

The main purpose of the present study was to clarify how an additional element reduces foveal bias in a manual localization task. We hypothesized that an abrupt change in landmark would draw observers' attention and hence reduce foveal bias. The results of Experiment 1 showed that an abrupt flash in the landmark near the target significantly reduced foveal bias. However, we could not differentiate the contributions of attention shift from those of memory averaging of the target and the 'attended' distracter. The results of Experiment 2 showed that a sudden disappearance of the distracter, which seemed to draw the observer's attention, significantly reduced foveal bias, suggesting that attention shift, not memory averaging, plays a key role in reducing foveal bias.

The results are consistent with previous reports that an additional element reduces foveal bias. In Sheth and Shimojo (2001), the distracter (a line) near the target reduced foveal bias. This finding and our results can be commonly explained in terms of attention shift towards the distracter. On the other hand, Kerzel (2002b) reported no reduction in foveal bias, rather a repulsion effect in which the target was localized away from the distracter.

The discrepancies between the results regarding the reduction of foveal bias might be due to the relative positioning of fixation, target, and landmark. In our experiment, the landmark was placed on a line passing through the target and fixation. A previous study demonstrated that such a configuration can reduce the frequency of foveal bias (Sheth & Shimojo, 2001). On the other hand, the distracter placed obliquely to the virtual line cannot affect foveal bias (Kerzel, 2002b). These discrepancies in the results nicely fit with the findings of Tse, Sheinberg, and Logothetis (2003) in that in comparison to the no-cue case, the attended region was significantly elongated along the line passing through the cue (with SOA of 106 ms or more) and fixation. The distracter in Kerzel's study (2002b) was placed orthogonally to the target; as a result the attended region elongated by the abrupt appearance of the distracter was unlikely to encompass the target, hence, had no effects on foveal bias. Thus, the relative positioning of the distracter, the target, and the fixation seemed to better explain the discrepancies between the two streams of studies.

A different line of thinking is that disruption in the balance of visual space due to changes in saliency might explain the reduction in foveal bias. It has been suggested that the luminance change of the object is salient enough to draw visual attention (Nothdurft, 2002). In our experimental paradigm both the flash and the disappearance of landmark involved luminance changes that entailed changes in saliency leading to disruption in the balance of visual scene. In the first experiment, we observed a SOA effect which had similar time course as reported by Posner (1980). However, in the second experiment, a prolonged effect of disappeared landmarks was observed. The difference in the time course of landmark effects between the two experiments can be explained by the existence of two types of spatially directed attentions: a transient attention in flashed conditions and a sustained attention in disappeared conditions (Nakayama & Mackeben, 1989). Specifically, the cue employed in Experiment 1 was transiently flashed while that employed in Experiment 2 remained disappeared until the response. Hence, the former and the latter cues might have entailed the transient and sustained attentions, respectively. Thus the two experimental conditions differing in temporal saliency exhibited differential SOA effects, i.e., a significant SOA effect in Experiment 1 and a non-significant SOA effect in Experiment 2.

Why was the attention shift so effective in reducing foveal bias? Here, we speculate that a re-organization of visuospatial coordinates takes place around an attended salient distracter in visual space. As described in the Introduction, foveal bias generally occurs even when observers are not provided with a fixation mark (Van der Heijden et al., 1999). It has been proposed that this is because visual space in memory is coded and remapped with a focused location as a center of representation (Kerzel, 2002a). In our experiments, the observers' attention was shifted towards the landmark that became salient due to flashing and vanishing. Therefore, it was likely that memory of visual space was re-organized with a focused location (i.e., the distracter position) as a center of representation. This idea is consistent with that of Werner and Diedrichsen (2002) that spatial memory was re-mapped on the basis of the distracters' position. Here, our results newly indicated that the trigger of the re-mapping might be an attention shift towards the distracter resulting in the reduction of foveal bias.

One may contend that our results resulted from an artifact of involuntary eye movements to transient changes in the distracter. The transient change is a bottom-up signal that automatically necessitates saccadic eye movements. Although observers were instructed to fixate on the central cross, they might have made saccadic eye movements towards the flashed or disappeared landmark. However, if the eye movements were the source of the reduction of foveal bias, a similar pattern would have been observed across three eccentricities. As it was, a significant reduction of foveal bias was observed only in the 9° eccentricity condition. Therefore, it seems untenable that eye movements were involved in modulating the magnitude of foveal bias in our study. Nonetheless, since eye position is a strong cue for accurate manual localization (Adam, Ketelaars, Kingma, & Hoek, 1993; Uddin, Ninose, & Nakamizo, 2004) it is imperative to address this issue in future research.

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