ATTENTION AND BIAS IN VISUOMOTOR LOCALIZATION

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ATTENTION AND BIAS IN VISUOMOTOR LOCALIZATION

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APPROVAL

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DEDICATION

This dissertation is dedicated to the people who have sacrificed their lives and/or valuables for the independence of Bangladesh.

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ABSTRACT

This dissertation is based on seven experiments that examined visuospatial memory of human observers. The first experiment was conducted under two general situations, one in which eye-movements during target presentation were restricted (attention condition) and the other in which they were allowed (saccade condition), while the rest of the experiments was confined to attention condition alone. However, in all experiments, a black dot as target was presented briefly at different locations on the frontoparallel plane of a cathode-ray-tube monitor. The viewing was binocular at a distance of 48–50 cm from fixation at the center of the monitor. After an interval of 150–500 ms following targets offset, observers had to point to the remembered location with the mouse cursor. Three parameters, namely, constant, variable, and vector of errors, that, respectively, are indices of veridicality, variability, and directionality of localization responses, were considered. The first experiment employing several target eccentricities and controlling potential confound of cursor appearing position tested the two-process model. Consistent with the model, larger constant error was observed in attention than saccade conditions. In addition, larger variable and vector of errors were also observed in attention condition. These results extended existing knowledge showing superior role of eye-movements over no eye-movements in localization performance on all measurements concerned. The next three experiments examined the mechanism modulating foveal bias by spatially cueing a non-target adjacent to the target with a variable stimulus onset asynchrony. The results unveiled that the point of regard is not 'memory-averaging' but 'attention-shift' towards the non-target that modulated foveal bias. The last three

experiments examined the origin of foveal bias by simultaneously presenting target with a cluster of non-targets. The results were interesting in that localization under the restriction of eye-movement was unbiased in 150 ms condition when there were non-targets in the display, while being biased towards fovea in 1000 ms condition regardless of the presence of non-targets. These findings that cannot be predicted from the two-process model suggest a dynamic characteristics of attention in relation to localization. In addition, in all experiments, only the vector parameter was found sensitive to different experimental conditions. This outcome is informative to suggest that localization can be reliably interpreted where vector of error is its parameter. Based on all results, here I propose a model which assumes that two factors, one is the point of attention or 'pseudo fovea' and the other is the point of fixation (not the fixation point) or 'fovea', can jointly account for the vector of error in localization.

Chapter 1: Introduction – An overview on visual spatial localization

1.1 A brief history of localization research

Identity and location are two fundamental aspects of object vision that could not be completely dissociated yet. In the late 1960s a distinction was proposed between two anatomically different neural systems that process either identity or location information (e. g., Ingle 1967). This early lack of concern with the role of spatial information in visuomotor behavior has been ascribed to the result of a passive stimulus-response model of perception (Butter, Kurtz, Leiby, & Campbell, 1982). According to the model, the perceiver is a passive recipient of environmental stimuli, and hence, s/he is not concerned with the processes of localization that guides the active search for new information.

The pioneers assessing separately the processing speed required for identification and localization were Dick and Dick (1969). Tachistoscopically, they presented one single letter in one of the four corners of an imaginary square centered on the fixation point. Observers were asked to report either the identity or the location of this letter. Their results showed that the observers were more accurate in localizing the letter than in identifying it. Based on this finding, they suggested that perception should be viewed as a hierarchical process where location information is processed before identity information. In a similar study, Smythe and Finkel (1974) found that observers recalled more spatial than identity information, hence, they argued that spatial information is processed more quickly than identity information, and that different mechanisms underlie spatial and object vision.

Later studies on visual search suggested that human vision operates in two sequentially arranged stages in which the operation of the second attentive stage is dependent on the output of the first preattentive stage (e. g., Sagi & Julesz, 1985a;

Treisman & Gelade, 1980). Generally, the first preattentive stage is assumed to operate in parallel, i. e., visual information presented across the visual field is believed to be processed at the same time. The second attentive stage is assumed to operate in a serial manner in which the amount of visual information processed per time unit is limited.

One theoretical notion is that the preattentive stage performs a feature analysis whereas the attentive stage is involved with localization and feature binding. According to the original feature integration theory (FIT), visual information is first analyzed into separate features (e.g., green, or round) which are represented in distinct feature maps (Treisman & Gelade, 1980). Thus, in preattentive vision, primitive features are detected and identified (Folk & Egeth, 1989; Green, 1991; Treisman & Gelade, 1980). Basically, preattentive processes signal what the identity is of a feature without signaling where it is. To localize a feature in the visual field the involvement of the second attentive stage is required.

A second theoretical approach suggested that the preattentive stage is capable of detection and localization whereas the attentive stage is capable of discrimination and identification (Sagi & Julesz, 1985a, b). This notion is just opposite to the original one of Treisman and Gelade (1980). Sagi and Julesz (1985a, b) claimed that the identification of even simple visual features requires the allocation of attentional resources. The preattentive stage is capable to detect feature differences or discontinuities and also able to localize these discontinuities. Thus, according to this view, the preattentive system can signal where without knowing what the target is, except that the target is different from non-targets. Whereas Treisman and Gelade (1980) assumed localization process to be conditioned upon feature identification processes, Sagi and Julesz (1985a) presumed identification processes to be conditioned upon localization processes (Nothdurft, 1992; Sagi & Julesz, 1985b).

Recently, a third theoretical point of view has been proposed (Cave & Wolfe, 1990; Treisman & Sato, 1990; Wolfe, Cave & Franzel, 1989). Like in the original FIT, it is assumed that the preattentive stage in human vision is capable of detecting simple features across the visual field (Treisman & Gelade, 1980). In contrast to the original FIT, in this view, features cannot be preattentively identified. Instead, localization as well as feature identification processes are assumed to be under attentional control, i. e., both processes are assumed to be performed by the attentive stage and conditioned on the output of the preattentive stage which only signals the presence of activity. Activity levels above some threshold indicate that some feature is present somewhere in the visual field. The identity and location of a feature can be reported only if attention is allocated (Cave & Wolfe, 1990; Treisman & Sato, 1990; Wolfe, 1994; Wolfe, Cave & Franzel, 1989). In other words, no conditional relationship is assumed between localization and identification processes.

More recently, Donk and Meinecke (2001) reported that identification processes are conditioned on localization processes. In their study, observers are not able to indicate the identity of a simple feature unless they are able to determine at least coarsely where that feature is. These results unequivocally show a superior fit of the localization model over the feature model and the unconditional model. Thus, their results are not in accordance with any account assuming that identification processes precede localization processes. The above review clearly showed that localization without identification or vice versa could not take place. That means, a complete dissociation of one from the other is yet to be done, and as such any theory dealing with identification or localization should take this matter into consideration.

1.2 Definition and classification of localization

To define localization is as difficult as to classify it. The term localization as defined most generally by Eggert, Sailer, Ditterich and Straube (2002) refers to the processing of visual spatial information from the retinal input to the motor or perceptual output. Both 'saccadic response' and the 'perceived location' in that sense can be subsumed under the same term 'localization'. However, localization studies are not confined to saccade and perception per se rather extended to behavior such as pointing. The pointing involving arm movement is often referred to as visuomotor localization and is performed with or without visual feedback which is referred to as closed loop or open loop pointing, respectively. The location of an object is determined either with respect to the observer or with respect to other objects in space. The former is referred to as absolute (or egocentric/intrinsic) localization while the latter as relative (or exocentric/extrinsic) localization. Finally, tracking moving objects is also a function of our visual system which is referred to as pursuit localization. Experiments dealing with pursuit localization require observers either to verbally respond whether a probe is in the same or different location as the object was (perceptual task) or to adjust manually the probe to the object location (visuomotor task). Thus, it appears that location of an object in space can be determined in a variety of ways. For readers interested in the area, I hereby present a simplified classification of localization in the following diagram (Figure 1) followed by descriptions of each. It is noteworthy that even though the nomenclature below is based on contributions of different authors working in this area it is not in complete agreement with their classification anyway. Also note that the following classification may be overlapping and may not represent an exhaustive list of localizations.

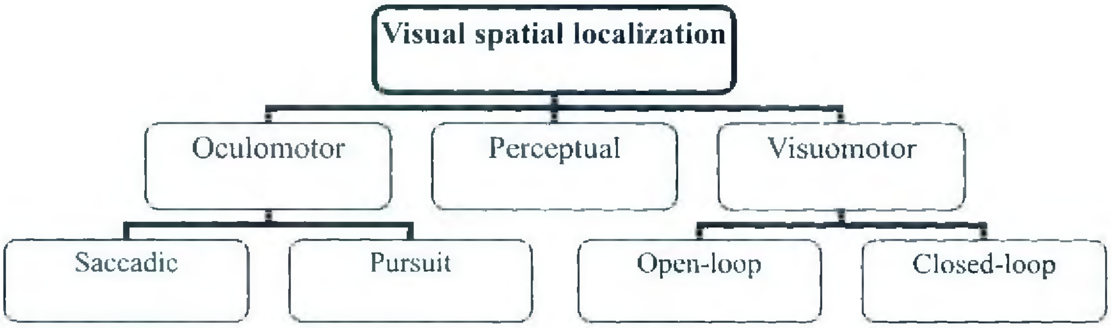


Figure 1: A diagram showing basic types of visual spatial localization.

1.3 Oculomotor localization

1.3.1 Saccadic localization

Saccadic localization (as distinguished from perisaccadic localization in which observers localize the target that appeared before, during, or after a saccade towards a flashed object) is indeed a saccadic eye movement to a target to bring its image onto the fovea for a clear vision. Saccades are usually reported to be inaccurate, undershooting the target by about 5-10% of the target's eccentricity, and requiring one or more catch-up or corrective saccades to correct these errors (e.g., Aitsebaomo & Bedell, 1992). Under conditions designed to promote best possible accuracy, saccades are, however, highly accurate with a mean constant error of about 1% of eccentricity and highly precise with a variable error of about 5–6% of eccentricity, rivaling the precision of relative perceptual localization task (Kowler & Blaser, 1995). Moreover, when directed to spatially-extended two-dimensional target as well as to point-target, saccades land near the center of gravity with comparable precision (He & Kowler, 1991, McGowan, Kowler, Sharma & Chubb, 1998; Melcher & Kowler, 1999; Vishwanath, Kowler, & Feldman, 2000).

Memory guided saccades are executed to the memorized target location while visually guided saccades are executed to a visible target location. Stanford and Sparks (1994) have reported that a pronounced systematic error is a consistent feature of memory guided saccade. Krappmann (1998) suggested that at least some of the distortions of memory guided saccades are due to inaccuracies in the sensory-motor coordinate transformations. Vergilino and Beauvillain (2001) reported that memory guided saccades are usually less accurate than those in visually guided saccades due to both systematic and variable errors. Thus it appears that localization is better under visually than memory guided saccades conditions.

1.3.2 Pursuit Localization

In everyday life, we track moving objects either attending covertly by fixating a certain point or attending overtly by smoothly moving our eyes with the moving objects. The latter is known as smooth pursuit or pursuit localization. When observers are asked to localize the final position of a moving target, the judged position is usually displaced from the actual position in the direction of motion (e. g., Hubbard, 1995). Kerzel (2000) in a systematic study found that briefly after target offset, the judged position is already displaced in the direction of motion. He argued that the shift results from eye movements after target offset that move the target's persisting image in the direction of motion. It is noteworthy that the direction of displacement was the major parameter of concern rather than accuracy and precision in the studies on pursuit localization.

1.4 Perceptual localization

Perceptual localization of a target is primarily determined by its retinal position. In perceptual localization, observers usually report, name, or judge the location of a target with respect to other object(s), for example, a numbered reference scale (e.g., Mateeff & Gourevich, 1983, 1984), a memorized array of digits (e.g., Van der Heijden, van der Geest, de Leeuw, Krikke, & Musseler, 1999) or a comparison stimulus (e.g., He & Kowler, 1991; Musseler, van der Heijden, Mahmud, Deubel, & Ertsey, 1999; Werner & Diedrichsen 2002; Kerzel, 2002b). The mode of responding in such tasks is verbal. The verbal mode together with the scale arrangement forces observers to indicate the remembered location in a coarse and approximate way. He and Kowler (1991) reported that perceptual localization was quite accurate and precise. Vishwanath and Kowler (2003) suggested that perceptual and saccadic localization is based on the computation of a precise central reference position, which coincides with the center of gravity in sequential scanning. Musseler et al. (1999) contended that the system controlling the saccadic eye movements is at the base of, and imports its properties in, the relative judgment task.

1.5 Visuomotor localization

It can also be referred to as manual localization in that the task is accomplished manually. In this type of task, observers usually (except for the study of Adam, Ketelaars, Kingma, and Hoek, 1993, where localization task is performed against a grid that masks all possible target locations after the target offset; hence relative visuomotor localization) have to reproduce the location of a peripheral target not with respect to other peripheral targets, but relative to either the fovea or an internal reference (Levi & Tripathy, 1996) by pointing with the mouse cursor (e.g., van der Heijden et al., 1999) or their finger (e.g., Bock, 1993; Enright, 1995). The important thing here is that in a closed-loop pointing response was biased towards fovea (e. g., Mateeff & Gourevich, 1983, 1984) whereas in an open-loop pointing it was towards periphery (e.g., Bock, 1993).

It is reasonable to assume that different types of localizations involve different modes that might affect localization. The mode is non-verbal in saccadic and visuomotor localization as opposed to verbal in the perceptual localization task. As Yamagishi, Anderson, and Ashida (2001) have demonstrated that visuomotor localization error in an open loop task was up to three times greater than the perceptual error for a short delay (200 ms) whereas similar for a long delay (4.2 s) suggesting an evidence for dissociation between the perceptual and visuomotor systems in humans. We speculate that these differences might have resulted from different modes–verbal vs. nonverbal.

On the other hand, an association between saccadic and visuomotor localization can be inferred from the following findings. Deubel (2004) has reported that the efficiency of landmarks in a saccadic task drops steeply for distracter eccentricities; the effect of distracter disappears beyond a horizontal spatial range of 3 deg from the target.

1.6 Parameters of localization

Performance in localization can be indexed in a number of ways depending on the type of task employed. The percentage of correct responses, the point of subjective equality (PSE), the threshold, and the magnitude of errors are commonly calculated parameters. The following are the most commonly used parameters which I adopted for my study.

1.6.1 Systematic/constant error or accuracy

An inverse index of veridicality of saccadic and visuomotor localization is calculated as the distance of mean response position of replicate measurements from the target (Adam et al, 1993). Using mathematical notations, the parameter could be expressed as follows:

$$\text{Constant error} = \sqrt{(\overline{X} - X)^2 + (\overline{Y} - Y)^2} \quad \text{------------------------------------} \quad (1)$$

1.6.2 Scatter or variable error or precision

An inverse index of variability of localization is calculated as the mean deviation of replicate measurements (Enright, 1995). By definition, mean deviation is the average of the distances of individual responses from their mean position.

$$\text{Variable error} = \frac{1}{n}\sum_{i=1}^{n}\sqrt{(\overline{X} - X_i)^2 + (\overline{Y} - Y_i)^2} \quad \text{----------------------------} \quad (2)$$

It is noteworthy here that constant and variable errors are independent, or orthogonal, measures (Howard & Rogers, 1995, p. 93).

1.6.3 Vector of error or bias

An index assumed to show magnitude and direction of error in localization is calculated as the mean distance of replicate measurements from the target (Enright, 1995).

$$\text{Vector of error} = \frac{1}{n}\sum_{i=1}^{n}\sqrt{(X_t - X_i)^2 + (Y_t - Y_i)^2} \quad \text{------------------------} \quad (3)$$

The above equation in effect can not manifest the direction of error. So, we adopt an alternative parsimonious measure that is represented by the difference between estimated eccentricity and actual eccentricity (for a similar measure, see also Newby & Rock, 2001, p. 162). Estimated eccentricity is calculated as the distance of mean response position from fixation. The smaller is the estimated eccentricity than actual eccentricity, the larger is the magnitude of error towards the fovea; the larger is the estimated eccentricity than actual eccentricity, the larger is the magnitude of error away from the fovea. It is noteworthy that the term 'vector' is used here to refer simply to foveopetal/central or foveofugal/peripheral directions and as such is not a genuine vector of mathematics.

Vector of error = Estimated eccentricity- Actual eccentricity

$$= \sqrt{(\overline{X} - X_0)^2 + (\overline{Y} - Y_0)^2} \; - \; \sqrt{(X_t - X_0)^2 + (Y_t - Y_0)^2} \qquad \text{-------} \qquad (4)$$

The symbols used in Equations 1, 2, 3, and 4 represent the following:

$\overline{X}$ is the X coordinate of mean response position, $\overline{Y}$ the Y coordinate of mean response position, X_t the X coordinate of target position, Y_t the Y coordinate of target position, X_i the X coordinate of ith response position, Y_i the Y coordinate of ith response position, X_0 the X co-ordinate of fixation mark, and Y_0 the Y co-ordinate of fixation mark.

1.7 Factors affecting localization performance

1.7.1 Cognitive factors: Attention and saccade

Attention plays a significant role in localization performance. Prinzmetal, Amiri, Allen, and Edwards (1998) have manipulated attention using a dual task paradigm in which observers were required to perform two tasks: (a) to indicate the identity of a centrally presented target letter (F or T) and (b) to determine by mouse cursor the location of a briefly presented peripheral dot (~ 7.5 deg eccentric). Identification and localization target were presented either simultaneously or successively. The results indicated that precision was greater with successive than with simultaneous presentation suggesting a role of attention in reducing the variability of responses.

Tsal and Bareket (1999) have manipulated attention using a spatial cueing paradigm in which the observers' task was to localize a small letter that appeared inside one of three large circles (left, center, and right) that was either validly or invalidly cued. The results showed that observers were more accurate and precise in localizing a target that was preceded by a valid cue than an invalid one. However, the effect was stronger at the center than at the periphery. In addition, attended peripheral target was biased towards the periphery. Newby and Rock (2001) using an inattention paradigm (originally adopted by Rock, Linnett, Grant, & Mack, 1992) localization performance was compared in three attention conditions: inattention, divided attention, and control. Their results were in agreement with previous findings (Prinzmetal et al., 1998; Tsal & Bareket, 1999). Recently, Tsal and Bareket (2005) investigated the effects of attention on localization with two converging manipulations of attention: focused attention vs. distributed attention. They reported that attention improved localization and the distribution of localization responses around peripheral stimuli were asymmetric, with a greater dispersion along the axis linking fixation to stimulus location relative to its perpendicular axis.

Saccade improves as well as impairs localization. For example, Adam et al. (1993) have reported that the accuracy in manual localization is lower when attention alone is involved in encoding target's location as compared to when attention followed by saccade is involved. Moreover, with the increase in exposure duration accuracy remains almost constantly impaired in the former condition but dramatically improves in the latter condition (Adam et al., 1993; Adam, Paas, Ekering, & van Loon, 1995). On the other hand, Ross, Morrone, Goldberg, and Burr (2001) have reported that when a target is flashed before, during or after a saccade, the visual space around the target appears to be compressed.

1.7.2 Spatial factors: Eccentricity, frame of reference, spatial frequency

A good number of studies have reported that localization performance deteriorates with the increase in target eccentricity (Osaka, 1973; Adam et al., 1995; Musseler et al., 1999). Adam et al. (1995) explained the phenomenon as reflecting physical properties of the retina in that stimuli at increasing distances from fixation point fall on retinal areas of decreasing acuity (Klein & Levi, 1987; Westheimer, 1982).

It has been also reported that the frame of reference affects localization performance (Carozzo, McIntyre, Zago, & Lacquaniti, 1999, 2002; Bridgeman 1991). For example, Eggert, Ditterich, and Straube (2001) have suggested that the mislocalization is partially due to a mismatch between egocentric and exocentric localization mechanisms. In their paradigm, a target was presented together with the fixation spot, which disappeared before the test flash. The authors assumed that in this paradigm the target was represented exocentrically with respect to the fixation while the test flash was egocentrically in the dark. It is likely that the peripheral target was perceived more centrally than the peripheral flash under two different localization strategies which in turn lead to mislocalization due to mismatch between them. Sheth and Shimojo (2001) reported that a distracter presented in memory-, retention-, and retrieval-phases can decrease the frequency of foveally biased reproduction of location of the target. Later, Sheth and Shimojo (2004) reported that a distracter presented in memory- and retrieval- phases enhances the precision of localization suggesting the superior role of exocentric frame of reference in localization. Lemay, Bertram, and Stelmach (2004) have demonstrated that when both exocentric and egocentric coding of location are possible, an exocentric strategy takes the dominant role over the other. Musseler et al, (1999) have reported that a spatially more extended comparison stimulus increases relative mislocalization, as compared with a less extended comparison stimulus.

1.7.3 Temporal factors: Exposure duration and retention interval

Temporal factors modulate localization performance greatly. For example, exposure duration found to have improved localization (e. g., Adam et al., 1993; Aitsebaomo & Bedell, 1992; Kowler & Blaser, 1995) whereas retention intervals deteriorated it (Sailer, Eggert, Ditterich, & Straube, 2000; Sheth & Shimojo, 2001; Werner & Diedrichsen; 2002). Sailer et al. (2000) have reported that foveal bias (error towards foveated region) was observed in the delayed saccadic localization but absent in the immediate saccadic localization. Sheth and Shimojo (2001) reported that the longer the retention interval the larger is the magnitude of foveal bias. Werner and Diedrichsen (2002) have reported that spatial memory distortions increased with longer retention intervals. Freyd and Johnson (1987) have reported that memory shift increases with retention interval for small intervals and instead of reaching some asymptotic value the memory shift then decreases with retention interval. The resulting U-shaped curve seems to be considered as resulted from two competing effects: a positive memory shift attributable to representational momentum which dominates at short intervals, and a negative shift attributable to memory-averaging effect which dominates at long intervals. Bertamini (1993) has reported similar findings for a target with implied motion. He reported that the memory distortion increased linearly when the retention interval was shorter than 300 ms after which it dropped to a smaller level. However, the author suggested that the drop cannot be explained by memory-averaging since a static target was used. Thus, it appears that retention interval for static target behaves differently from that for dynamic target.

From the above brief review, it is evident that location and identity of an object is virtually inseparable. The localization performance of a visual stimulus is affected by many factors, namely, attention, saccade, frame of reference, temporal characteristics of the stimuli, etc. Therefore, one should take those factors into account while formulating a model of visual spatial localization, thus enhancing the robustness of the model in question. The next section is devoted to present an overview of a formal model of localization followed by highlighting its limitations.

1.8 The two-process model

The two-process model of visual spatial localization is the outcome of systematic studies by Adam et al. (1993). The authors examined how quickly and accurately location information is processed by employing a visuomotor localization task in which a single target appeared in one square of an imaginary 25 x 19 grid. Target exposure duration was varied between 25 and 300 ms employing a backward masking stimulus that controlled the functional lifetime of the target stimulus. Observers pointed to the remembered location with the mouse cursor available at the fixation. Results showed two salient components in function relating stimulus duration and accuracy in localization: the first component is a steep rise during the first 50 ms followed by a gradual rise from 100 ms onwards. They interpreted these phenomena as reflecting sequential operation of the attention and eye movement systems. Accordingly, they proposed a two-process model of visual spatial localization. The model states that visual attention is shifted to the target area; this conveys coarse location information followed by a saccade providing fine location information. Even though Adam et al. (1993) formally proposed this kind of model it was, however, anticipated by Atkinson and Braddick (1989) who contemplated the possibility that "different processes may underlie localization performance at different levels of precision" (p. 184).

The role of eye-movement is critically important for superior performance in localization. To test this proposition, Adam et al. (1993) compared localization performance under steady fixation and eye movement conditions. In steady fixation condition observers were instructed to maintain fixation steadily on the fixation mark whereas in eye movement condition they were instructed to saccade to target as soon as it appeared. Results revealed that, with or without eye movements, localization performance rapidly improved over the first 50 ms whereas, thereafter markedly improved in eye movement condition but not in the steady fixation condition. The first finding, combined with evidence obtained in cueing and search experiments that the time needed to shift attention is in the order of 50–60 ms (e. g., Treisman & Gelade, 1980), nicely fits with the idea that the attention system is involved in localizing very short duration stimuli.

The effect of masking on localization was also examined to provide further support for the model. The masking in their paradigm can be distinguished from conventional one in the following ways. The masking stimulus remained visible throughout the response phase and was highly structured since its elements formed a systemic response grid. So, it is logical that masking not only interfered but, perhaps, also facilitated the processing of the target by providing anchor or reference points. This potential benefit is expected at long stimulus durations where the eye movement system is postulated to mediate fine localization. Adam et al. (1995) assessed these predictions by examining localization in three conditions: no-mask, short duration mask (100 ms), and long duration mask (available until response). Results demonstrated that relative to no-mask condition, both long and short duration masks interfered with short-duration target while only the long-duration mask facilitated the long–duration target.

Another prediction that spatial and symbolic precues would differentially affect localization was also tested. Spatial pre-cues induce exogenous attention whereas symbolic pre-cues do endogenous attention. Exogenous and endogenous attentions have different time courses in achieving maximum effects. Specifically, exogenous precues achieve maximal effect at 50 ms where symbolic pre-cues achieve it at 500 ms (Shepherd & Muller, 1989). Adam, Huys, van Loon, Kingma, and Paas (2000) tested those predictions by manipulating duration of pre-cue (71, 400, and 1000 ms) and type of pre-cue (spatial and symbolic). Their results showed that short durations (i.e., 71 and 400 ms) spatial pre-cues improved localization whereas symbolic pre-cues did not. In contrast, both symbolic and spatial pre-cues improved performance equivalently in long duration (1000 ms) condition. This pattern of differential pre-cueing benefits provided further support for the two-process model. Thus, the model proved to be a promising theory of visual spatial localization.

1.9 Limitations of the model

The model ignored important parameters necessary for the interpretation of localization behavior. There are reports that accuracy is differentially contingent upon attention and saccade conditions (Adam et al., 1993) and precision is upon exocentric and egocentric conditions (Sheth & Shimojo, 2004). This appears to suggest that accuracy and precision conveys meaningful information under specific conditions of localization. Recent investigations revealed bias as an index of localization performance informing mechanisms underlying memory for location. As reported, location of a peripheral target is generally reproduced towards the fovea, a phenomenon known as foveal bias (Mateeff & Gourevich, 1983). Since foveal bias occurs regardless of the presence or absence of a fixation point (Kerzel, 2002a; van der Heijden et al., 1999), the phenomenon is unlikely to stem from memory-averaging between the target and the fixation point (Sheth & Shimojo, 2001). Rather, representation of space in memory appears to be re-organized around a focused or attended position (Kerzel, 2002b). Thus, accuracy, precision, and bias conveys meaningful information as independent measure of localization.

The predictive ability of the model is very limited. For example, the model is about static target not dynamic one and as such cannot be generalized. It is based on a narrow band of target eccentricity, e. g., a maximum of 6.6 deg and hence can not predict performance beyond that. It cannot predict performance when target accompanies non-targets as happens to be the case in everyday life. The model is constructed based on a two-dimensional display even though object of interest often appears three-dimensionally.

The model, though considers attention as one of the processes, does not delineate the characteristics of attention in relation to localization. For example, it did not point out the heterogeneous spread of attention across visual fields as reported in some studies (Tsal & Bareket, 1999, 2005). These studies reported that distributions of localization responses around peripheral stimuli were asymmetric, with greater dispersions along horizontal than vertical and radial than tangential axes. Also, visual field performances were reported in some tasks, e.g., in search and tracking tasks and in spatial relocation memory task (He, Cavangh, & Intriligator, 1996; Genzano, Nocera, & Ferlazo, 2001) attributing them to attentional resolution. However, reconciliation of these finings with the two-process model seems a far cry.

Thus, the model appears crude with many limitations. In the words of Adam et al. (1995) "--------- Indeed, the task to construct a more specific model is rather formidable: The way the brain achieves the final unitary percept of position is largely a mystery. Nevertheless, we hope that the present work has contributed to at least a preliminary understanding of the processes underlying object localization, and that it, by providing a concrete hypothesis, will stimulate further research on this important topic in human visuomotor behavior".

1.10 The present concern

The present concern was to verify the two-process model while controlling the potential confound of cursor position. The effect of target distance reported in the study of Adam et al. (1993) might have been confounded with cursor position. There are evidences that cursor appearing position affects localization performance. For example, van der Heijden et al. (1999) have warned that one has to be very careful with the interpretation of the data obtained in position judgment experiments with cursor setting as the task, because a shift of reference point is easily induced. Hubbard and Ruppel (1999) have also urged similar caution that cursor position and fixation point may have been used as references for location judgments, resulting in landmark attraction or memory-averaging. Therefore, in the first experiment, we controlled cursor appearing position and included several target eccentricities with a maximum of 15 degree (which was about 6.6 degree in the study of Adam et al, 1993). Moreover, we avoided using masking stimulus since there are reports that it has facilitating as well as interfering effects on localization (Adam et al., 1995)

Chapter 2: Experiment 1 – Test of the two-process model

2.1 Purpose

The purpose of the present experiment is to replicate the study of Adam et al. (1993) by measuring not only constant error, but also variable and vector of errors in localization performance under three conditions: steady fixation (SF) during presentation of target for 1000 ms, hereafter referred to 1000SF; changing fixation (CF) during presentation of target for 150 and 1000 ms, hereafter referred to 150CF and 1000CF, respectively. According to the model, the higher performance is expected in the 1000CF and 150CF conditions than in the 1000SF condition since the former two conditions involve eye movements and the latter attention.

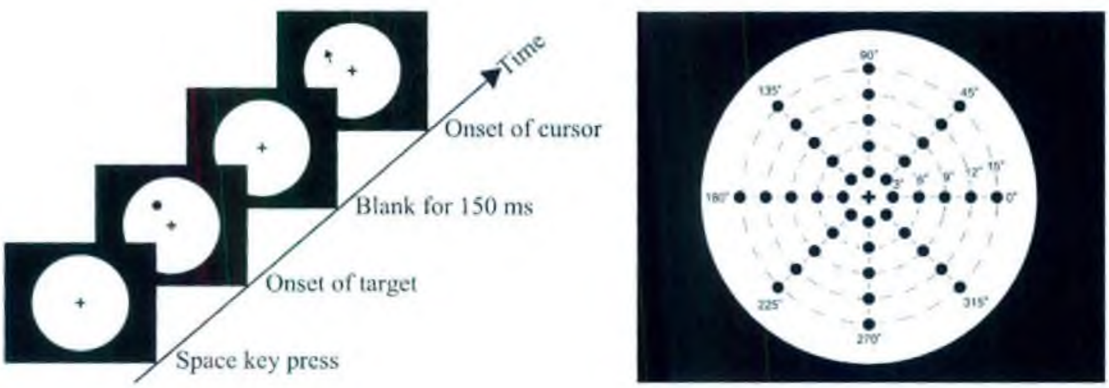
2.2 Methods

2.2.1 Participants

Six graduate psychology students (II, HS, TY, DK, TK, UK; three female and three male) of Kyushu University volunteered as observers. They were between 23 and 35 years old with a median age being 24.5 and all had normal or corrected-to-normal vision. All observers except the first author were naive of the purpose of the experiment but were extensively experienced in psychophysical experiments.

2.2.2 Apparatus and stimuli

The stimuli were presented on a 40.5 cm x 30.5 cm color CRT monitor (IIYAMA HM204D) with a pixel resolution of 1024 x 768 and a refresh rate of 100 Hz. An IBM Net Vista A30P computer interfaced with the CRT monitor. The shape and size of the monitor was changed to a circular screen of about 37° in diameter by means of a window cut in a sheet of black paper concentric with the black fixation mark (+), 1° in length and 0.1° in width, (luminance 0.56 cd/m^2) located at observer's eye level. Observers' head was stabilized with a chin-and-forehead rest. Eye movements were recorded by Limbus Tracker Method (Kyushu Keisokuki K.K. Model QM1-101) to check for observers' ability to properly maintain fixation on the fixation mark during 1000SF condition. The voltage output of the tracker was fed on-line through a low-pass 50 Hz filter to a 12-bit A/D converter (Kyushu-Kyohan K. K., Condition Catcher-Multi function data logging system) that sampled eye position at every 10 ms. The digitized voltages were stored for later use. Target stimulus was 1° black circular disc (luminance 0.56 cd/m^2) presented on gray background (luminance 62.2 cd/m^2) within 30° of visual field. Programs for generating stimuli were written by Visual Basic language.



(a) (b)

Figure 2: Schematic representations of (a) the stimulus sequence, where the cross is the fixation mark, the black dot is a target, and the arrow is a mouse cursor, and (b) possible target locations. The black rectangle is a window cut concentric with the fixation point.

2.2.3 Procedure

Observers positioned in front of the computer monitor at a viewing distance of 40 cm. They viewed binocularly in a dimly lit room (illuminance 17.5 lx). At the beginning of each trial, articulating a ready signal 'hai' (a Japanese word meaning yes) the experimenter pressed space key that initiated the target to have appeared randomly at one of the 40 possible locations comprising 5 target eccentricities – 3, 6, 9, 12, and 15° and 8 target directions – 0, 45, 90, 135, 180, 225, 270, and 315°; 0° being at right horizontal axis and magnitudes increase counterclockwise. The mouse cursor appeared after a fixed interval of 150 ms following target offset at one of the same eight random locations as target directions. It appeared 3° away from target and disappeared after a trial is over. Thus, the confounding effect of cursor position on localization is minimized and held constant in all possible combinations of conditions since it appears at equidistant position around the target (see Figure 2 for schematic).

Three stimulus conditions were employed: (i) observers were instructed to maintain gaze steadily at the fixation mark while target appeared for 1000 ms, the condition hereafter referred as 1000SF (ii) observers were instructed to quickly saccade to and fixate on target that appeared for 150 ms and 1000 ms, the conditions hereafter referred as 150CF and 1000CF, respectively. In all conditions, observers the task was to point with cursor to the remembered location and to confirm the location by pressing the left button of the mouse; eye movements to the cursor while localizing were permitted. After each trial is over, observers had to refix on the always-visible fixation mark. A total of 16 training trials preceded experimental trials in the 1000SF condition so that observers can be able to maintain fixation during that condition. Experimental trials were started only when the experimenter was confirmed by checking eye movement record that observer was able to maintain gaze on the fixation mark. Each observer completed 18 blocks of 40 trials each in two-day session. S/he completed 3 replications (9 blocks) per day in about a 45-minute session including a 5-minute-break each before second and third replications. Order of stimulus conditions followed a partially Latin square design while the experiment followed a completely three-factor within-group design. Each observer performed a total of 720 (3 stimulus conditions x 5 eccentricities x 8 directions x 6 replications) trials.

2.2.4 Basic data

Three parameters, namely, constant, variable, and vector of errors were calculated. For all parameters, mean response position from six trials of each observer was initially calculated. Distance between this mean position and the target location was expressed as constant error. Distances of individual trials from mean response position were summed up to calculate variable error. The lower the magnitude of constant and variable errors, the higher was the accuracy and precision of localization, respectively. Finally, distance of fixation from mean response position was calculated to represent estimated eccentricity. Actual eccentricity was subtracted from estimated eccentricity to represent vector of error. The negative value is an index of foveal bias and positive a peripheral bias. The constant, variable, and vector of errors were obtained for 40 locations per observer and the unit of measurement in all cases was of degree in visual angle. Mathematical notations are shown in the Introduction section.

2.2.5 Data analysis

Data were subjected to a three way repeated measures ANOVA. In addition, vector of error was assigned to ninety-five-percent confidence interval (95% CI).

2.3 **Results**

Constant error for each stimulus condition is plotted in Figure 3 as a function of target eccentricity (upper left panel) and target direction (lower left panel). A three way (3 stimulus conditions x 5 target eccentricities x 8 target directions) repeated measures ANOVA yielded significant main effects of stimulus conditions, $F_{2, 10}$ = 29.985, $p < 0.01$; target eccentricities, $F_{4, 20} = 9.226$, $p < 0.01$; target directions, $F_{7, 35}$ = 7.615, $p < 0.01$; significant interactions between stimulus conditions and target eccentricities, $F_{8, 40} = 2.954$, $p < 0.05$; stimulus conditions and target directions, $F_{14, 70}$

= 4.564, p < 0.01; and target eccentricities and target directions, $F_{28, 140}$ = 1.876, p < 0.01. Post hoc tests (Ryan's method, p < 0.05) showed significant difference between all possible pairs of stimulus conditions, the highest accuracy in the 1000CF condition followed by that in the 150CF condition and the lowest being in the 1000SF condition (t_{10} = 7.661, t_{10} = 2.851, and t_{10} = 4.810, respectively). Further, post-hoc tests showed larger constant error for larger eccentricity and for the upper field target. Post-hoc tests of the simple main effect for interaction between stimulus condition and target eccentricity showed eccentricity effect for 1000SF and 150CF conditions, larger error for larger eccentricity. Post-hoc tests of the simple main effect for interaction between stimulus condition and target direction showed direction effect for 1000SF and 150CF conditions, larger error at upper visual field. However, an upper lower asymmetry was pronounced in 1000SF condition at the target eccentricity exceeding 6°.

Variable error for each stimulus condition is plotted in Figure 3 as a function of target eccentricity (upper middle panel) and target direction (lower middle panel). A three-way (3 stimulus conditions x 5 target eccentricities x 8 target directions) repeated measure ANOVA yielded significant main effects of stimulus conditions, $F_{2, 10}$ = 12.105, p < .01; target eccentricities, $F_{4, 20}$ =60.538, p < .01, and interaction thereof, $F_{8, 40}$ = 8.724, p < .01. Post hoc pair-wise comparisons (Ryan's method, p <.05) showed that localization performance in the 1000CF condition was significantly more precise than in either of the other two conditions (t_{10} = 19.605 and t_{10} = 17.823, respectively). Furthermore, ANOVA performed for each stimulus condition separately showed that variable errors increased with the increase of target eccentricities in 1000SF and 150CF conditions and remained unchanged in 1000CF condition.

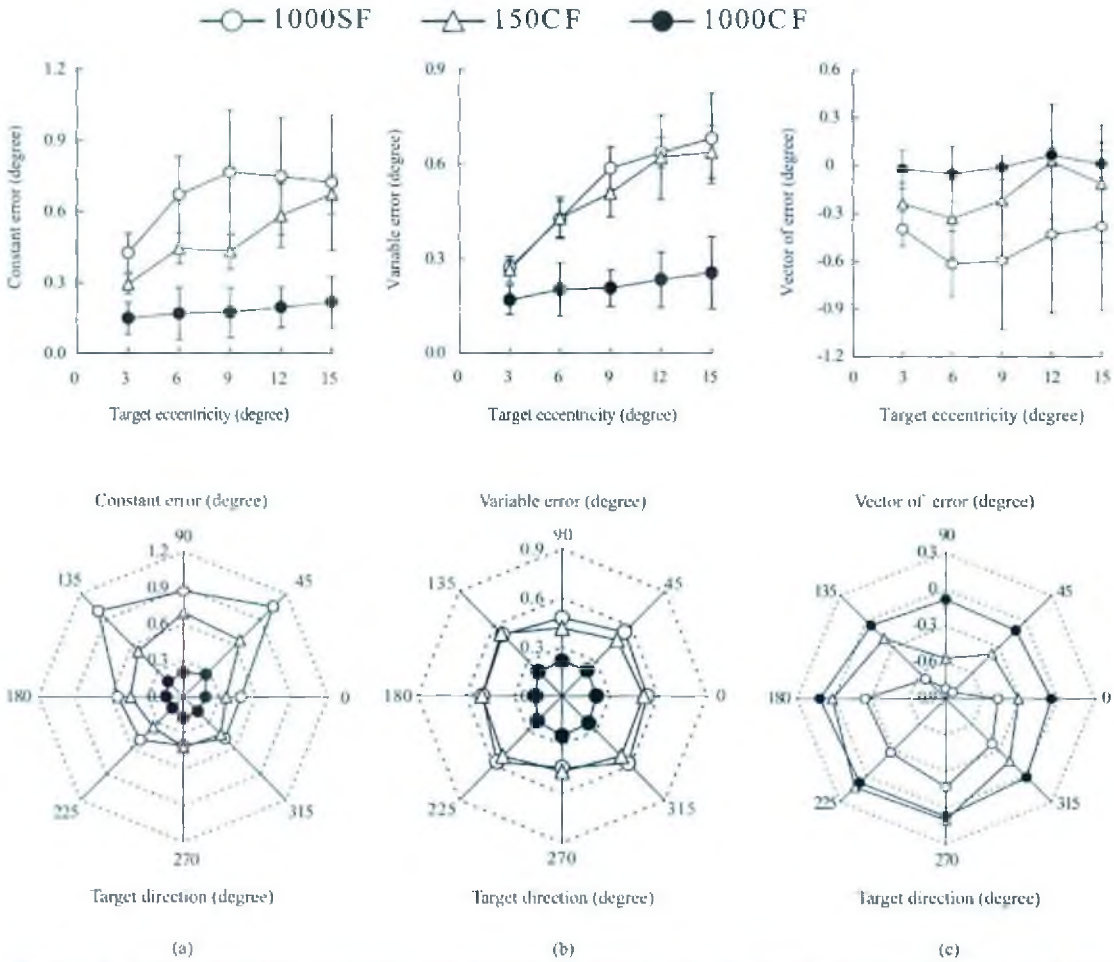


Figure 3: Mean constant, variable, and vector of errors are plotted in panels (a), (b), and (c), respectively, as a function of target eccentricity (top panel) and target direction (bottom panel). Each datum point in top panel is the average from 48 (6 observers x 8 target directions) and in bottom panel is the average from 30 (6 observers x 5 target eccentricities) measurements. The lower are the magnitudes of constant and variable errors the higher are the accuracy and precision, respectively. Values along vertical axes of figures in bottom panel are the radii of dotted circles to represent the magnitude of errors. The negative values of vector of error represent foveal bias while the positive values peripheral bias. Vertical bars denote ±1 standard error of the mean (S. E. M.).

Vector of error for each stimulus condition is plotted in Figure 3 as a function of target eccentricity (upper right panel) and target direction (lower right panel). A three-way (3 stimulus conditions x 5 target eccentricities x 8 target directions) repeated measure ANOVA yielded significant main effects of stimulus condition, $F_{2, 10} = 12.105$, $p < .005$; and target direction, $F_{7, 35} = 9.460$, $p < .001$. Interactions between stimulus condition and target direction as well as target eccentricity and target direction were significant ($F_{14, 70} = 2.030$, $p < .05$ and $F_{28, 140} = 2.656$, $p < .001$, respectively). Post hoc pair-wise comparisons (Ryan's method) showed that foveal bias was significantly larger in the 1000SF condition than in either of the other two conditions ($t_{1, 10} = 4.856$, $p < .05$; $t_{1, 10} = 3.117$, $p < .05$, respectively). Post-hoc tests for the simple main effects of interaction between stimulus condition and target direction showed that foveal bias was larger at the upper visual field and it was for 1000SF and 150CF conditions. Furthermore, simple main effects for the interaction between target direction and target eccentricity showed that foveal bias at upper field was significantly larger at target eccentricities exceeding 6°. Specifically, an upper lower asymmetry was observed beyond 6 deg target eccentricities.

2.4 Discussion

The present experiment demonstrated significantly larger constant errors in attention condition (1000SF) which are consistent with the predictions of the two-process model. In addition, variable and vector of errors were also larger in that condition. The important things to note here that the foveal bias occurred not only in attention (1000SF) condition but also in saccade to brief target (150CF) condition (as determined by 95% CI). It is plausible to think this similar outcome in conditions 1000SF and 150CF might be due to some common mechanism. Since Helmholtz (see Fuchs, 1938) speculated foveal displacement as due to attention and later Kerzel (2002b) argued foveal bias as not due to memory-averaging between fixation and target an attentional account seems a likely candidate to explain the similar outcome in our present experiment. This attentional account is further reinforced by the findings that foveal bias in saccade to long duration target (1000CF) condition was shown non-significant (as determined by 95% CI which we did not report in this dissertation). We hypothesize that an attentional binding between fixation and target is the origin of foveal bias. The binding is assumed to be intact in attention condition, whereas disrupted partially in saccade to brief target condition and entirely in saccade to long duration target condition. Please note that the temporal effect on foveal bias has been demonstrated successfully across Experiments 5, 6, and 7. Thus our idea of attentional binding proved to be valid. We will elaborate this point in general discussion section.

Chapter 3: Experiment 2 – Mechanism that reduces foveal bias

3.1 A brief review on attention and memory in foveal bias

Long ago Helmholtz (see Fuchs, 1938) reported that location of an object in space is perceptually displaced towards the fixation point, a phenomenon which he called 'concentric shrinkage of the visual field'. An example is this: if one attempts to indicate the center of a line one of whose ends is fixated, the peripheral half will be made too large. That is to say, the other end will be displaced towards the fixation point. Hering (see Fuchs, 1938) thought that anatomical-physiological inferiority of the peripheral retina to central retina is the direct cause of concentric shrinkage. However, the idea of inferiority proved false in the later investigation.

The point of regard is usually the center of attention. Experimental substantiation of this has been published by Lipp (see Fuchs, 1938) who found precisely that displacement of a presented object occurred not towards the fixation point, but when its location differed, towards the center of attention that serves as fovea which Fuchs termed pseudo-fovea. Moreover, the attended portion of the field exhibited a marked clarity. In a word Lipp found that displacement proceeds towards that part of the visual field which is attended, viz, towards the object of greatest clarity. In view of this, Fuchs classified errors of displacement as instances of confluence phenomena.

Later, the displacement towards fovea is reported as a distortion in visual short term memory (Sheth & Shimojo, 2001). This displacement or foveal bias was reported to have occurred regardless of the presence or absence of an actual fixation point (Van der Heijden et al., 1999). This implies that the fixation point served merely as a cue for fixation and not as a visual landmark (Sheth & Shimojo, 2001; see also Deubel, 2004) suggesting that foveal bias might not result from memory-averaging 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).

Thus, a question 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 was displaced towards a landmark/distracter; a distortion they termed landmark- attraction or more generally 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. Thus, reproduced locations do not appear to be consistently biased towards the distracters. Therefore, we can neither accept nor refute memory-averaging as a mechanism underlying the reduction in foveal bias.

An alternative mechanism might be attention-shift towards landmark. 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 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 that delimits generalization over a stationary target.

Further evidence favoring attention-shift as a mechanism comes from the following studies involving static target. For example, Werner and Diedrichsen (2002) found attraction towards landmarks. However, they found repulsion when the target was very close to the landmark. Thus, their findings are equivocal showing attraction as well as repulsion. More recently, Prinzmetal (2005) reported landmark attraction effect for briefly presented two dots: a target dot and a landmark dot. With one button press, observers indicated the position of the target relative to the landmark and also the absolute position of the target dot. Observers indicated, in addition to correct relative position, the target as being closer to the landmark than it actually was. The author termed the effect as *location assimilation* for which *spatial averaging* is the integration rule and attention is the underlying mechanism.

From the above review, one can not conclude which of two mechanisms, attention-shift or memory-averaging, is responsible for reducing foveal bias. To arrive at a general conclusion, we dissociated attention-shift from memory-averaging in next three experiments employing a spatial cueing paradigm.

3.2 Purpose

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

3.3 Methods

3.3.1 Participants

Nine graduate psychology students (ST, TY, TS, YY, YM, DK, RI, NN, and HS; 4 females and 5 males) of Kyushu University volunteered. 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.

3.3.2 Apparatus and stimuli

The stimuli were programmed in Delphi 6 with DirectX and displayed on a 19-inch color CRT monitor (Nanao, FlexScan 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/m²) of 0.33° in diameter and the landmarks were 4 identical bars (luminance 10 cd/m²) 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/m²) subtended 1° in length and 0.04° in width and centered on the screen. The background was black (luminance 0.1 cd/m²). The target was presented randomly at an eccentricity of 3, 6, or 9° from the fixation mark at one of 4 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. 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/m²) on for about 80 ms with a SOA of 0, 106.4 or 212.8 ms. Thus, a total of five experimental conditions which followed a two factor within group design were included. The basic paradigm of the experiment is schematized in Figure 4.

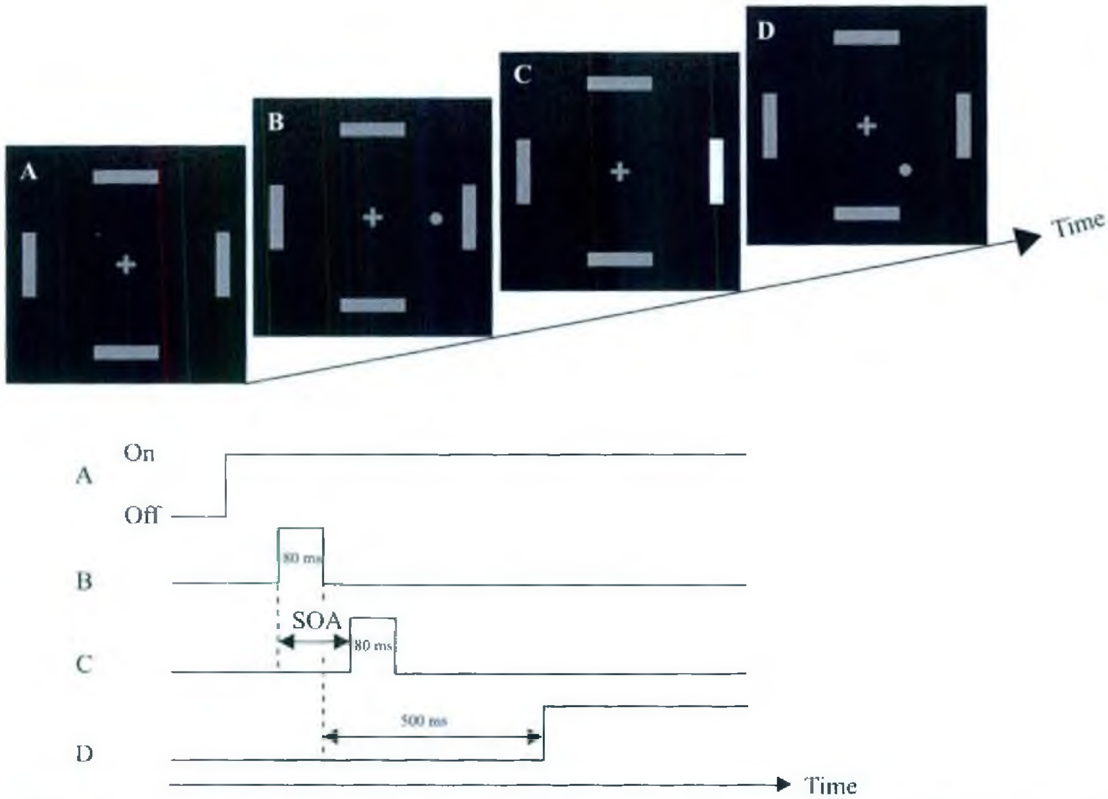


Figure 4: A general schematic representation of the experimental protocol. A: Four bars serving as landmarks were presented. B: A target (dot) appeared 50 ms after the space key was pressed. C: The landmark nearest the target flashed on for 80 ms (Experiment 2) or disappeared until response was made (Experiment 3) or disappeared until space key was pressed after response (Experiment 4). D: The mouse cursor appeared 500 ms after target offset.

3.3.3 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. 50 ms later a target appeared for 80 ms, during which time observers were required to continue maintaining fixation while memorizing 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°

arms concentric with the center of the target. The observers' task was to position the cursor in 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 6 blocks of 48 trials each in a single session lasting about 30 min including breaks between blocks. The first 5 blocks each consisted of randomly intermixed conditions of 4 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).

3.3.4 Basic data

Following Equation 4 mentioned in the introduction, estimated eccentricity was calculated for mean response to a particular target location. Estimated eccentricity was subtracted from actual eccentricity to represent vector of error. The negative value is indicative of foveal bias and the positive value peripheral bias. The magnitudes of error for each eccentricity were averaged over 4 target directions and 4 repetitions to obtain the mean error per condition per observer. The mean error 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.

3.3.5 Data analysis

The basic data were subjected to a two-way (5 experimental conditions × 3 target eccentricities) repeated measure ANOVA. Moreover, ANOVAs were conducted separately with data for flashed landmark conditions.

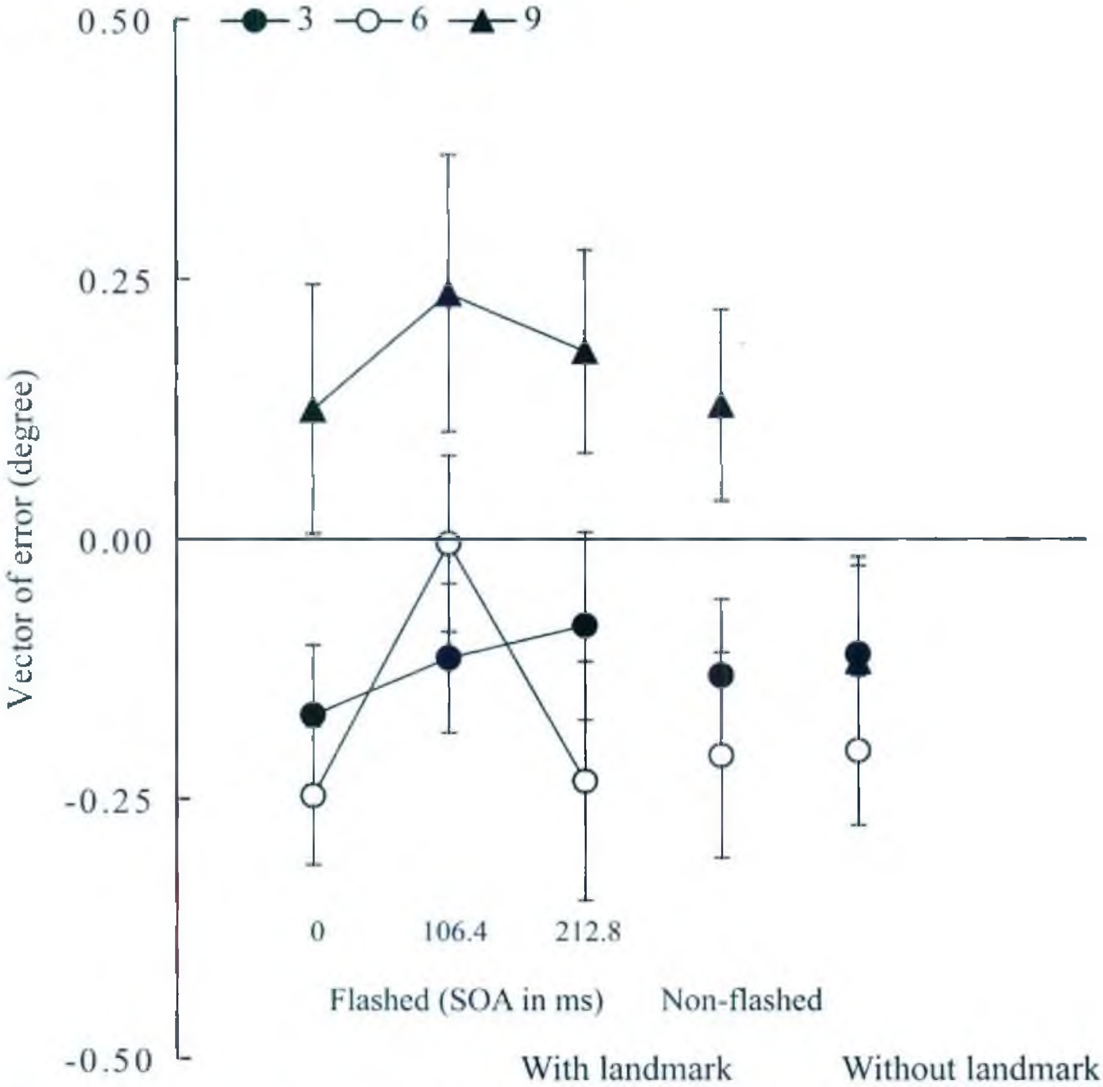


Figure 5: Mean vector of error plotted as a function of experimental condition ('with landmark': flashed with SOAs of 0, 106.4 and 212.8 ms, and 'non-flashed' and 'without landmark') and target eccentricity (3: filled circle, 6: open circle, and 9: triangle) in degree of visual angle. Each datum point is the average from 144 measurements (4 target directions × 4 repetitions × 9 observers). The negative values along vertical axes represent foveal bias and positive values peripheral bias. Vertical bars denote ±1 standard error of the mean (S. E. M.).

3.4 **Results**

Mean vector of error as a function of experimental condition and target eccentricity is plotted in Figure 5. 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.

The above results are in agreement with the expectation that landmark conditions (flashed and non-flashed) would exhibit lower foveal bias than without landmark condition. However, they are not in agreement with the expectation that flashed conditions would exhibit 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 conditions. 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. This suggestion fits fairly well with the report of Deubel (2004) that the distracter's effect largely disappears beyond a horizontal range of 3 deg from the target (see also Prinzmetal, 2005 who reported bias towards a landmark which is 1.7° distant from a target). Moreover, the SOA showing significant reduction of foveal bias was congruent with that causing large cueing effects (Posner, 1980).

3.5 Discussion

The 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 disappeared. 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.

Chapter 4: Experiment 3 – Dissociating attention-shift from memory-averaging

4.1 Purpose

In Experiment 2 we could not dissociate attention-shift from memory-averaging since landmark was visible in both flashed and non-flashed landmark conditions. Here we adopted a strategy where landmark was disappeared in stead of being flashed. If attention-shift takes place then landmark conditions (no matter whether disappeared or not) should exhibit lower foveal bias than no-landmark condition. On the other hand, if memory-averaging takes place then non-disappeared landmark condition should exhibit lower foveal bias then other two conditions.

4.2 Methods

4.2.1 Participants

Nine graduate psychology students (ST, TS, HS, SS, MI, SR, KS, DK, and AY; 6 females and 3 males) of Kyushu University volunteered as observers. 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.

4.2.2 Apparatus and stimuli

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

4.2.3 Procedure

All procedures were identical to Experiment 2.

4.2.4 Basic data

The basic data calculation was the same way as in Experiment 2.

4.2.5 Data analysis

The data were subjected to a two-way (5 experimental conditions × 3 target eccentricities) repeated measure ANOVA. Moreover, ANOVAs were conducted separately with data for disappeared landmark conditions.

4.3 **Results**

Mean vector of error as a function of experimental condition and target eccentricity is plotted in Figure 6. 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 pair-wise 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 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 deg 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 conditions whereas they both differ significantly from without landmark condition (t_{16} = 4.102, p <.001; t_{16} = 3.057, p <.001, respectively).

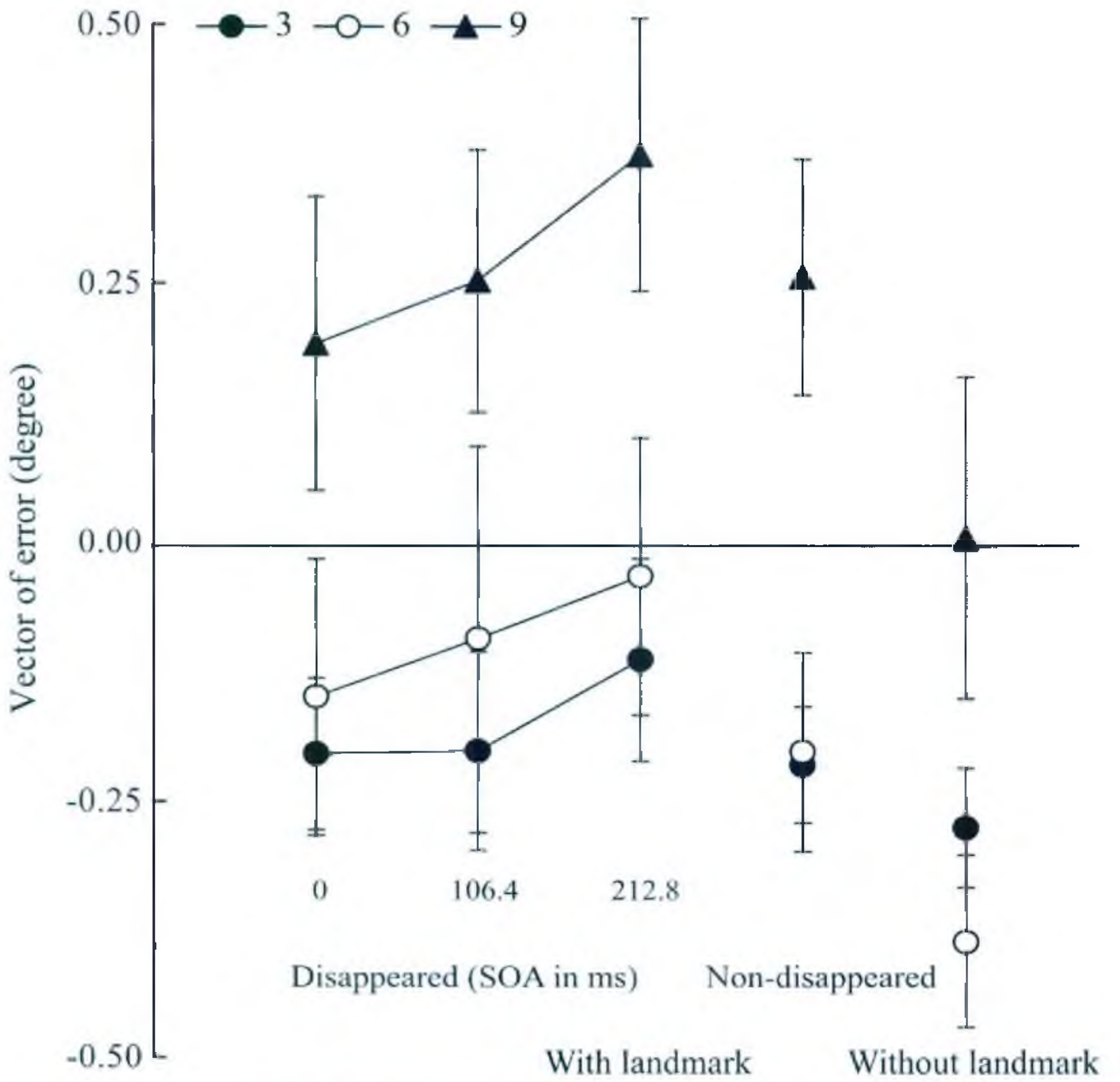


Figure 6: Mean vector of error plotted as a function of experimental condition ('with landmark': disappeared with SOAs of 0, 106.4 and 212.8 ms, and 'non-disappeared' and 'without landmark') and target eccentricity (3: filled circle, 6: open circle, and 9: triangle) in degree of visual angle. Each datum point is the average from 144 measurements (4 target directions × 4 repetitions × 9 observers). The negative values along vertical axes represent foveal bias and positive values peripheral bias. The larger is the magnitude the larger is the bias. Vertical bars denote ±1 standard error of the mean (S. E. M.).

4.4 Discussion

The above results clearly show that attention-shift was the crucial factor that reduced foveal bias. As in Experiment 2, foveal bias was significantly reduced when the SOA was 106.4 ms. Reduction in foveal bias was also observed for a SOA of

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.

The experiment supported our argument that attention-shift, not memory-averaging, reduced foveal bias. However, we cannot argue from these experimental findings that attention-shift also increases foveal bias as it reduces. To provide firm evidence for attention hypothesis, we carried out the next experiment in which we manipulated the eccentricity of landmark while holding the target eccentricity constant. Since in Experiment 2 a spatial range of 3 degree was found effective, we placed the landmark at 3 and 9 degrees while the target at 6 degree. Thus attention-shift could be directed foveofugally and foveopetally.

Chapter 5: Experiment 4 – Further support for attention-shift hypothesis

5.1 Purpose

To provide further support for attention-shift hypothesis we manipulated eccentricity of landmark in two ways, 3 degree (near landmark) versus 9 degree (far landmark), while holding the target eccentricity constant at 6 degree. We expected that larger foveal bias would be observed in near than far landmark conditions.

5.2 Methods

5.2.1 Participants

Nine graduate psychology students (GS, XW, YA, KT, TK, YY, TY, DK, NY; 4 females and 5 males) of Kyushu University volunteered as observers. The participants' ages ranged from 20 to 26 years with a mean age of 23.5 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.

5.2.2 Apparatus and stimuli

The stimuli were identical to those used in Experiments 2 and 3. The experimental conditions were identical to those in Experiment 3 except for the following: the landmark was either 6 degree or 12 degree eccentric and the target was 9 degree. Thus, the experiment included 9 conditions [(2 landmark conditions (near or far landmark) x 4 spatial cueing (disappeared with SOAs of 0, 106.4, 212.8 ms and non-disappeared)) + no-landmark condition as a baseline].

5.2.3 Procedure

All procedures were identical to Experiment 3 except for the following. The disappeared landmark did not appear after response. Instead, other 3 landmarks disappeared following response and all landmarks reappeared following space key press for the next trial. Since the disappeared landmark did not reappear the effect of feedback on localization performance remained controlled. Observers received 2 blocks of trials each in a single session lasting about 15 minutes. The first block consisted of randomly intermixed 8 conditions (2 landmark conditions x 4 cue conditions) and the last one only of the base line condition. Thus, each observer performed a total of 144 trials (9 conditions × 4 target directions × 4 repetitions).

5.2.4 Basic data

The basic data calculation was the same way as in Experiments 2 and 3. Since a single target eccentricity was used, a total of 81 (9 conditions × 9 observers) basic data were available for further analyses.

5.2.5 Data analysis

The data were subjected to one-way repeated measures ANOVA.

5.3 **Results**

Mean vector of error as a function of experimental conditions is plotted in Figure 7. The dotted line shows the base line condition. A one-way ANOVA revealed significant effect ((F (8, 64) = 5.955, $p < .001$). Post hoc comparisons (Ryan's Method, $p < 0.05$) showed larger foveal bias for near landmark than far landmark conditions. To examine the effect of SOA, two additional ANOVAs for far and near landmark conditions were computed. Consistent with Experiment 3, no SOA effect was observed in both conditions. Interestingly, when non-disappeared landmark condition was included in the analyses, only for the near landmark condition was the F-ratio significant ((F (3, 24) = 8.337, $p < .001$); all SOA conditions exhibited larger foveal bias than non-disappeared condition.

Following the non-significant SOA effect, we collapsed the data across respective landmark conditions and ran a one-way (mean of near landmark, mean of far landmark and no-landmark) repeated measures ANOVA. The results showed significant F-ratio ((F (2, 16) = 4.716, p < .05). Post hoc comparisons showed only the experimental pair was significantly different (t_{16} = 3.041, p < .05).

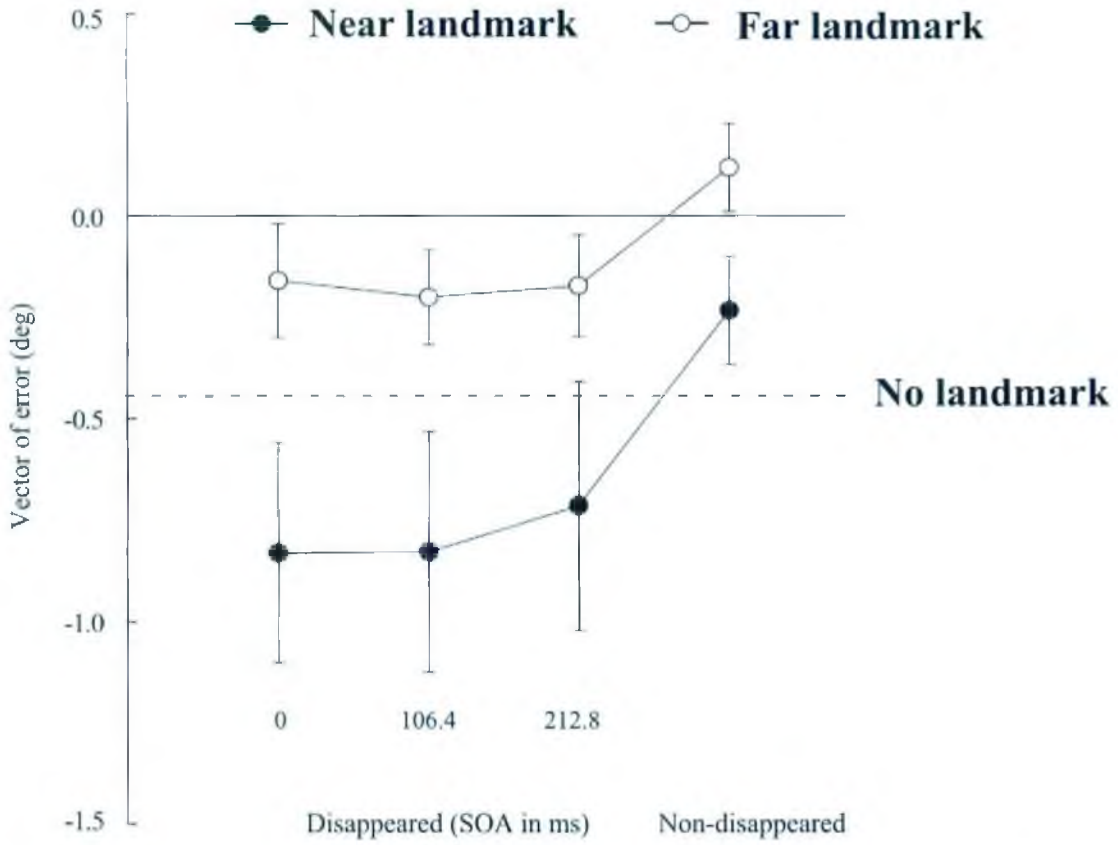


Figure 7: Mean vector of error in near and far landmark conditions plotted as a function of spatial cueing ('disappeared landmark' with SOAs of 0, 106.4 and 212.8 ms, and 'non-disappeared landmark'). Each datum point is the average from 144 measurements (4 target directions × 4 repetitions × 9 observers). The negative values along vertical axes represent foveal bias and positive values peripheral bias. The larger is the magnitude the larger is the bias. The dotted line represents the magnitude of error in the 'no landmark' condition. Vertical bars denote ±1 standard error of the mean (S. E. M.).

5.4 Discussion

As expected, foveal bias was larger when landmark was closer to fixation than it was farther from it. Further, there was no SOA effect in both near and far landmark conditions which is an evidence of a prolonged effect of SOA as observed in Experiment 3 also. However, compared to no-cue condition, the prolonged effect of

SOA significantly enhanced foveal bias only in near landmark condition. In other words, no-cue (non-disappeared landmark) condition behaved differently from all cue (disappeared landmark) conditions in near condition alone. This signifies that attention-shift towards landmark was substantially stronger when landmark was on the same side of the fixation relative to target that in turn enhanced attentional force at fixation to increase foveal bias.

Indeed, non-disappeared near landmark condition did not differ from non-disappeared far landmark condition when we compared them separately (F value was not reported here since it was non-significant). This supports our idea that attentional force at fixation was significantly enhanced by cueing near landmark condition compared to that in far condition. However, why experimental conditions (near and far) did not differ from baseline condition (no-landmark) cannot be immediately answered. One reason might be that the magnitude of accentuation or attenuation of attentional force at fixation due to the attention-shift, respectively, to near and far landmark, was not sufficient to make a difference. However, this being not our interest and beyond scope, we leave this matter for future research.

Chapter 6: Experiment 5 – Role of distracters in localization

6.1 A brief review on frame of reference in relation to parameters

Spatial localization of objects is a fundamental task for the human cognitive system. Scanning of an object's location in a short period is inaccurate, and it usually takes a prolonged time to comprehend the exact location (Atkinson & Braddick, 1989). In addition to temporal factors, cognitive factors such as attention (Tsal & Bareket, 1999, 2005) and eye movements (Adam et al., 1993) play a critical role in localization. Accuracy in manual localization is lower when attention alone is involved in encoding the target location compared to when attention followed by saccadic eye movements is involved (Adam et al., 1993). Moreover, with increasing exposure durations, accuracy improves in the latter condition alone (Adam et al., 1993, 1995). This pattern of results indicated that mechanisms for memorizing an object's location consist of two stages, the first stage involves an attention-shift towards the target location conveying coarse location information, and the second stage involves saccadic eye movements bringing the target onto the fovea thus conveying fine location information.

Bias is another parameter that also appears to inform about the underlying mechanisms in memorizing location of a visual target. Location of a peripheral visual target is generally reproduced towards the fovea (Mateeff & Gourevich, 1983). This phenomenon is known as foveal bias. Since foveal bias occurs regardless of the presence or absence of a fixation point (Kerzel, 2002a; Van der Heijden et al., 1999), the phenomenon is unlikely to stem from memory-averaging between the target and the fixation point (Sheth & Shimojo, 2001). Rather, representation of space in memory appears to be re-organized around a focused or attended position (Kerzel, 2002b). Thus, investigation of stimulus conditions yielding foveal bias is useful to reveal the mechanisms constructing memory representation for the location of a visual object.

The magnitude of foveal bias is dependent on retention interval. Sailer et al. (2000) reported that foveal bias was observed in memory-based saccadic localization but not in reflexive saccadic localization. Sheth and Shimojo (2001) reported that the longer the retention interval the larger was the magnitude of foveal bias. A prolonged retention interval seems to provide egocentric cues such as eye position with a stronger role in the registration of visual space in memory. On the other hand, the fact that there was no foveal bias in saccadic localization of a target exposed for short duration (Sailer et al., 2000) indicated that in reflexive localization, the dominance of an egocentric frame of reference in constructing memory representation was weak. Thus, the frame of reference in which target location is coded and memorized appears to be irrefutably a vital factor in determining the quality of memory representation and, hence, localization.

It has been shown that a target can be stored in either an egocentric (Carozzo et al., 1999), or exocentric (Bridgeman, 1991), or in both frames of reference simultaneously (Carozzo et al., 2002). Moreover, interactions between egocentric and exocentric cues in manual localization have been suggested. For example, Eggert et al. (2001) suggested that inaccuracy in localization during fixation was partially due to a mismatch between egocentric and exocentric localization mechanisms. Sheth and Shimojo (2001) reported that a distracter presented in memory-, retention-, and retrieval- phases could decrease the frequency of foveally biased reproduction of location of the target. Later, Sheth and Shimojo (2004) reported that a distracter presented in memory- and retrieval- phases enhanced the precision of localization.

Furthermore, they reported that exocentric cues could suppress egocentric cues in constructing memory for location, that is, information derived from exocentric cues may take priority to determine memory for location of a visual target. Lemay et al. (2004) suggested that when both exocentric and egocentric coding of location were possible, an exocentric strategy was used.

Even though localization researches have explicitly addressed the issue of frame of reference in relation to localization the conditions under which a particular frame of reference is preferred were not explored so far. In other words, the origin of preferential use of a particular frame of reference is yet to be known. By addressing this issue one can in effect expose the mechanism underlying the preference for a particular frame of reference that in turn will unveil the origin of bias in localization.

6.2 Purpose

The present experiment tries to explore the origin of bias in localization by presenting target with a cluster of non-targets while manipulating exposure duration in two ways, 150 ms (short) and 1000 ms (long). As a control, target is presented without accompanying non-targets in 50% of the trials. We expected that attentional binding between fixation and target will be weakened when target accompanies non-targets and also in short exposure duration condition. The weak binding in turn will lead to the reduction in foveal bias.

6.3 Methods

6.3.1 Participants

Five psychology graduate students (TY, SS, TK, UK, and DK; two females and three males; including the first (UK) and second (TK) authors) of Kyushu University volunteered as observers. They were between 23 and 36 years old with a median age of 25 years, and all had normal or corrected-to-normal vision. Observers TY, SS, and DK were naïve of the purpose of the experiment. All observers were extensively experienced in psychophysical experiments and TY, TK, and DK were adept in recording eye movements. TY, TK, UK, and DK also participated in Experiment 1 where they were required to maintain a fixed gaze while stimuli were presented; and eye movement data showed that they performed the tasks successfully.

6.3.2 Apparatus and stimuli

The stimuli were displayed on a 19-inch color CRT monitor, (Nanao, Flex Scan T761) with a pixel resolution of 1024 x 768, and a refresh rate of 75 Hz. A Sony Video Audio Integrated Operation (VAIO) PC interfaced with the monitor, and controlled the presentation of stimuli and collection of data. The stimuli and experiments were programmed in Delphi 6. Luminance of stimuli was measured using a luminance meter (MINOLTA, LS-100). Two stimuli conditions, with and without distracters, were employed. In the with distracters conditions, stimuli consisted of one white circle (luminance 29.2 cd/m^2) as a target and eight grey circles (luminance 7.4 cd/m^2) as distracters presented on a neutral grey background (luminance 16.3 cd/m^2). Target and distracters differed by only a single feature, namely, luminance. Both the target and distracters subtended a 1° visual angle. Target was presented at a distance of 9° from the fixation mark (luminance 0.36 cd/m^2), the fixation mark composed of vertical and horizontal black lines 1° in length and 0.1° in width located at the center of the display.

The target was presented at one of 8 pre-determined directions: 45, 90, 135, 180, 225, 270, 315 and 360° in polar angle; 360° was used to represent the right horizontal direction and values thereafter decreased clockwise. Distances and directions of distracters were determined as follows: the distances of four near and four far distracters were fixed at 4.5° and 13.5° from the fixation mark, respectively. Directions of distracters were jittered by a randomly selected angle within a range of ± 30° for a pre-determined set: 45, 135, 225, and 315°. The display containing a target and jittered distracters was presented to the observers. In the with-distracters conditions, directions of distracters were repeated throughout a session while the direction of the target varied randomly. In the without distracters conditions, the target was presented without accompanying distracters.

6.3.3 Procedure

The experiment was conducted in a dimly lit room (illuminance: 23 lx). Observers sat at a viewing distance of 48 cm from the CRT display. A chin-and-forehead holder was used to stabilize visual field and to match the eye level to that of the fixation mark. Observers initiated the experiment by pressing the space key, which made the fixation mark appear at the center of the display. 500 ms after the appearance of the fixation mark, a 1000-Hz tone burst of 70 dB including a background noise of about 35 dB was presented as an auditory warning signal for 13 ms through a speaker in the computer. The stimuli were displayed 500 ms after initiation of the auditory signal (Figure 8). During presentation of stimuli for 150 or 1000 ms, observers were asked to maintain their gaze on the fixation mark. After an interval of 150 ms from offset of stimuli, a mouse cursor appeared at the fixation mark. The observers' task was to drag the cursor to the remembered location of the target and press the left button of the mouse so that the screen coordinates of the cursor could be recorded. Instructions emphasized on accuracy rather than on speed, and eye movements during localizing were allowed. After pressing the mouse, the trial finished, the observers re-fixed their gaze on the fixation mark, and the next trial continued as previously.

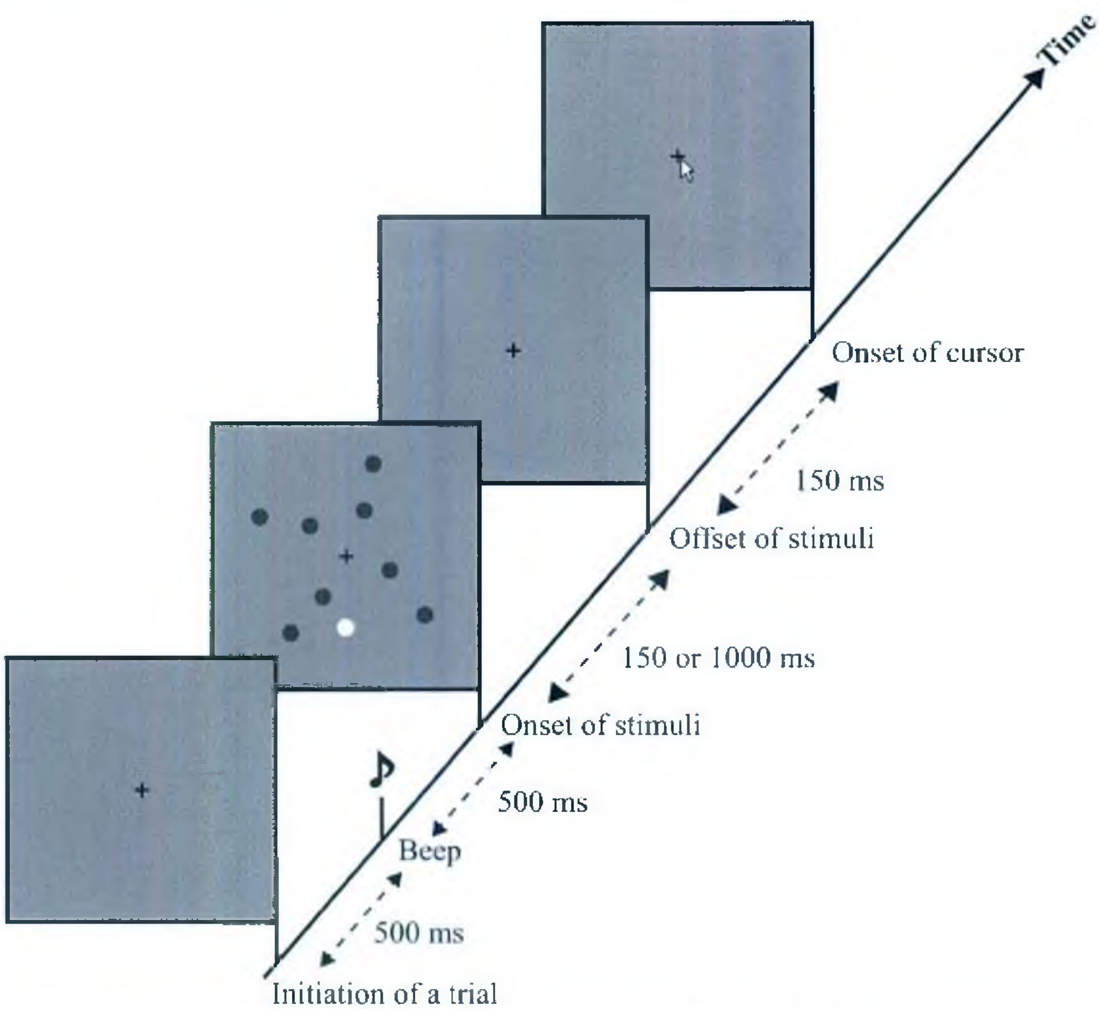


Figure 8: A general schematic representation of the experimental setting in which the cross represents the fixation mark, the white dot is a target, the black dots are non-targets, and the arrow is a mouse cursor.

Observers attended two separate sessions, one for each stimulus duration (150 and 1000 ms), consisting of 7 blocks with 16 trials each. Thus, each observer performed a total of 2 x 7 x 16 = 224 trials. The order of sessions was counterbalanced across the observers while the order of trials in a block was randomly intermixed (2: with or without distracters x 8: target directions). Between blocks, observers were allowed to take a break for as long as 5 min. The first block of each session in all 3 experiments was regarded as a practice block and was excluded from statistical analyses.

6.3.4 Basic data

We calculated three different parameters of localization, i.e., constant error, variable error, and estimated eccentricity. Common to all parameters, for each observer we first calculated the mean response position from six repeated responses to each target position. Distance of the target from this mean position was used to represent the constant error. Mean of distances from individual responses from the mean response position represented the variable error. The lower were the magnitudes of constant- and variable errors, the higher were the accuracy and precision of localization, respectively. Finally, distance of fixation from mean response position was calculated to represent estimated eccentricity. When estimated eccentricity was smaller than actual eccentricity, it referred to foveal bias, and when it was larger, it referred to peripheral bias. Constant errors, variable errors, and estimated eccentricities were separately averaged over 8 target positions to obtain corresponding data for analysis. Units for basic data in all cases were in degrees of visual angle.

6.3.5 Data analysis

Basic data for constant errors, variable errors, and estimated eccentricities were subjected to two-way (2: with or without distracters x 2: 150 and 1000 ms exposure durations) repeated measures ANOVA. In addition, basic data for estimated eccentricities were assigned to 95% confidence interval (CI). Basic data calculation and its analysis were applicable to subsequent experiments.

6.4 **Results**

Mean constant errors for with and without distracter conditions are plotted in

Figure 9a as a function of exposure duration. An ANOVA showed that neither the main effects of with/without distracters and exposure duration, nor their interactions showed significant effects (F (1, 4) = 1.776, p >.05; F (1, 4) = .002, p >.05; F (1, 4) = 4.74, p >.05, respectively).

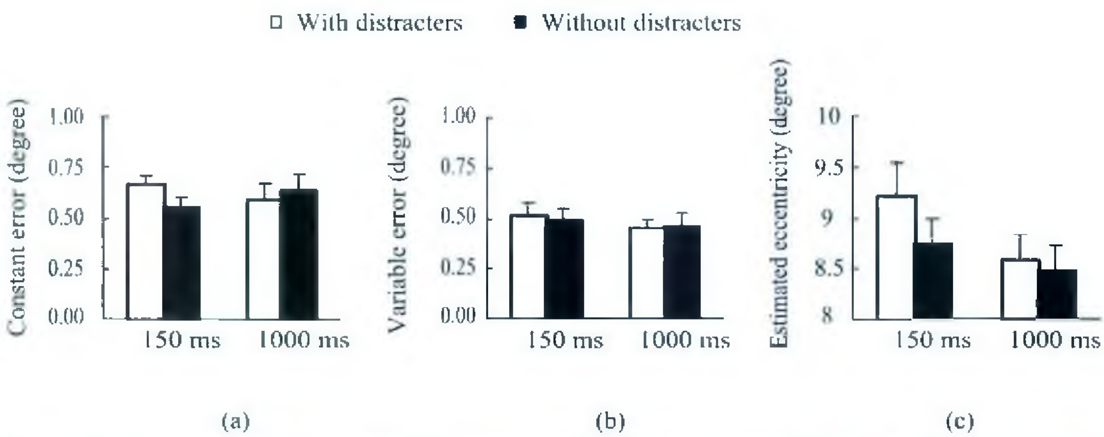


Figure 9: Mean constant error, variable error, and estimated eccentricity for with and without distracters conditions plotted as a function of exposure duration in (a), (b), and (c), respectively. The lower are the magnitudes of constant and variable errors the higher are the accuracy and precision, respectively. The smaller (larger) are the magnitudes of estimated eccentricity than actual eccentricity (here 9 degree) the larger are the foveal (peripheral) biases. Each vertical bar in panels (a) and (b) denotes ±1 standard error of the mean (S. E. M.) and that in the right panel denotes a ninety-five-percent confidence interval (95% CI)

Mean variable errors for with and without distracter conditions are plotted in Figure 9b as a function of exposure duration. An ANOVA showed that neither main effects nor their interaction was significant. (F (1, 4) = 3.437, p >.05; F (1, 4) = .419, p >.05; F (1, 4) = .450, p >.05, respectively).

Mean estimated eccentricities for with and without distracter conditions is plotted in Figure 9c as a function of exposure duration. A two-way repeated measures ANOVA (2: with or without distracters × 2: 150 or 1000 ms exposure durations) revealed that the main effects of context and exposure durations were significant (F (1, 4) = 25.987, p < .01; F (1, 4) = 19.177, p < .05, respectively). Interaction between these two variables was also significant (F (1, 4) = 11.713, p < .05). Post-hoc tests for interaction showed that duration was significant (F (1, 8) = 29.888, p < .001) when distracters were present but not significant (F (1, 8) = 5.255, $p < .1$) when distracters were absent. Moreover, effects of the presence/absence of distracters were significant (F (1, 8) = 36.775, $p < .0005$) when duration was short but not significant (F (1, 8) = 1.976, $p > .05$) when duration was long. A 95% CI revealed that localization was unbiased in the presence of distracters with short duration, and was biased towards the fovea regardless of the presence or absence of distracters with long duration.

6.5 Discussion

The results demonstrated the effects of non-targets on the vector parameter. Of particular interest is the finding (determined by 95% CI) that localization in the presence of non-targets was unbiased under short duration and biased towards fovea under long duration conditions. These results lead us to speculate that the vector of error in localization is perhaps determined by the relative strength of attention allocated to the fixation and to the target. This idea of explaining bias in terms of attention is originally proposed by Fuchs (1938) who coined the term pseudo fovea to refer to the point of attention. That means the point of attention can serve as a point of fixation when their locations differ. Let's see how this idea can be fitted with our results. The amount of attentional resources allocated, in the present experiment, to the fixation is likely to be reduced when target and non-targets are presented. This reduction is further accentuated by the relatively short exposure duration. As a result, the resultant attentional force could not attract target towards fixation. On the contrary, the relative strength of attentional force is expected to be high at fixation under long exposure duration resulting in the bias towards it. The results are interpreted in greater detail in general discussion section.

If attentional account works then one should expect larger foveal bias in constant configuration than in varied configuration of non-targets since visual search for a target as reported by Chun and Jiang (1998) is faster in the former condition. The reason behind this expectation is that attentional allocation to fixation would be less affected in invariant configuration condition resulting in larger foveal bias. This prediction was verified in Experiment 6 where the position of distracters remained the same in 50% of the trials and changed in the rest of the trials.

Chapter 7: Experiment 6 – Configuration of distracters as affecting localization

7.1 Purpose

We examined the effect of configuration of distracters on the magnitude of foveal bias. Configuration was manipulated as variant and invariant where the position of each distracter changes with trials in the former condition while remain the same in the latter. We expected that attentional binding will be weakened in variant configuration condition leading to the reduction in foveal bias. The basis of our expectation is the findings of Chun and Jiang (1998) that visual search is faster in invariant than in variant context conditions.

7.2 Methods

7.2.1 Participants

The same five observers in Experiment 5 participated in Experiment 6. Except for UK and TK, observers TY, SS, and DK were naïve of the purpose of the experiment.

7.2.2 Apparatus and stimuli

Apparatuses were the same as those used in the Experiment 5, and stimuli were identical except for the following: two conditions, *invariant* and *variant distracters* were randomly intermixed. Directions of distracters remained the same throughout a session in the *invariant distracters* conditions but were varied, i.e., newly constructed, in each trial in the *variant distracters* conditions. Directions of distracters in both stimuli conditions were jittered as in the first experiment.

7.2.3 Procedure

The experimental procedure was the same as in the Experiment 5.

7.2.4 Basic data

Basic data calculation was same as in Experiment 5.

7.2.5 Data analysis

Analysis was also done in the same way as in Experiment 5.

7.3 **Results**

Mean constant errors in invariant and variant distracter conditions are plotted in Figure 10a as a function of exposure duration. An ANOVA showed that neither main effects of configuration and exposure durations, nor their interaction were significant ($F(1, 4) = 1.306$, $p > .05$; $F(1, 4) = .013$, $p > .05$; $F(1, 4) = 2.998$, $p > .05$, respectively).

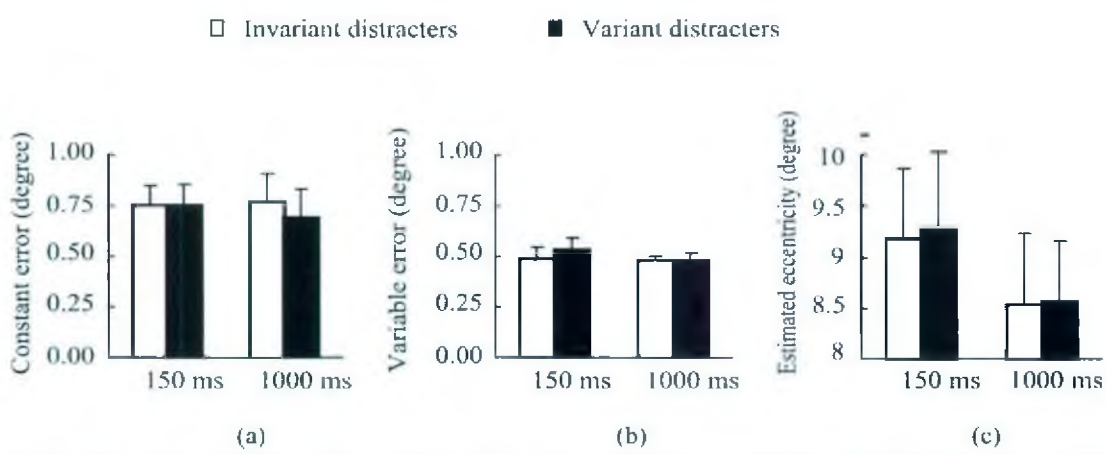


Figure 10: Mean constant error, variable error, and estimated eccentricity in invariant and variant distracter conditions plotted as a function of exposure duration in (a), (b), and (c), respectively. The lower are the magnitudes of constant and variable errors the higher are the accuracy and precision, respectively. The smaller (larger) are the magnitudes of estimated eccentricity than actual eccentricity (here 9 degree) the larger are the foveal (peripheral) biases. Each vertical bar in panels (a) and (b) denotes ±1 standard error of the mean (S. E. M.) and that in the right panel denotes a ninety-five-percent confidence interval (95% CI)

Mean variable errors in invariant and variant distracter conditions are plotted in Figure 10b as a function of exposure duration. An ANOVA showed neither the main effects of configuration and exposure durations nor their interaction were significant ($F(1, 4) = 6.361$, $p = .0652$; $F(1, 4) = .446$, $p > .05$; and $F(1, 4) = 4.171$, $p > .05$, respectively).

Mean estimated eccentricities in invariant and variant distracter conditions are plotted in Figure 10c as a function of exposure duration. A two-way repeated measures ANOVA (2: invariant or variant distracter × 2: 150 or 1000 ms exposure duration) revealed the significant main effects of configuration (F (1, 4) = 14.457, $p < .05$) and exposure duration (F (1, 4) = 9.668, $p < .05$). Interaction between the two variables was not significant (F (1, 4) = 0.475, $p > .05$). A 95% CI revealed that localization was not biased with long or short durations regardless of the type of distracters - variant or invariant.

7.4 **Discussion**

The results provided supporting evidence favoring our hypothesis. Consistent with the prediction, the magnitude of foveal bias was larger in the invariant than in the variant distracter conditions (8.85 and 8.92^{o}, respectively). Moreover, both variant and invariant conditions yielded unbiased localization as determined by 95% CI. Furthermore, our results replicated the effects of duration on foveal bias. As in Experiment 5, distracters were effective only when exposure duration was 150 ms. Thus our results well reflected the idea of relative strength of attention at fixation causing foveal bias.

However, we cannot rule out the likelihood that a spatial-shift of the target towards remote non-targets lead to an unbiased localization in both invariant and variant conditions. In Experiments 5 and 6, half of the distracters were less eccentric (hereafter referred 'near distracters') and the other half were more eccentric (hereafter referred 'far distracters') than the target. To verify whether spatial-shift towards non-targets is the underlying cause of unbiased localization, we separated near and far distracters to be used in the next experiment. If spatial shift takes place, then larger foveal bias is expected to be observed in near than far distracter conditions.

Chapter 8: Experiment 7 – Eccentricity of distracters as affecting localization

8.1 Purpose

To preclude the possibility that spatial-shift towards remote non-targets might have lead to an unbiased localization in Experiments 5 and 6, we separated near and far non-targets in the present experiment. If spatial-shift takes pace then larger foveal bias would be observed in near non-targets condition.

8.2 Methods

8.2.1 Participants

Five observers including four from Experiments 5 and 6 participated in the present experiment. The new observer SN replaced observer DK. Except for UK and TK, other observers were naïve of the purpose of the experiment.

8.2.2 Apparatus and stimuli

Apparatuses were the same as in Experiments 5 and 6, and stimuli were identical to those in the previous experiments except for the following: two conditions, *near* and *far distracters*, were used. Near and far distracters were, respectively, 4.5 and 13.5° apart from the fixation mark. Directions of distracters remained the same throughout a session and were jittered as in the previous experiments.

8.2.3 Procedure

The experimental procedure was the same as in the Experiments 5 and 6.

8.2.4 Basic data

Basic data calculation was same as in Experiments 5 and 6

8.2.5 Data analysis

Analysis was also done in the same way as in Experiments 5 and 6

8.3 Results

Mean constant errors in near and far distracter conditions are plotted in

Figure 11a as a function of exposure duration. An ANOVA showed that neither main effects nor their interaction was significant (F (1, 4) = .325, p >.05; F (1, 4) = .777, p >.05; F (1, 4) = 1.397, p >.05, respectively).

Mean variable errors in near and far distracter conditions are plotted in Figure 11b as a function of exposure duration. An ANOVA showed a significant main effect of eccentricity of distracter (F (1, 4) = 20.805, p < .05), the near distracter yielding higher precision. However, main effect of exposure duration and interaction were not significant (F (1, 4) = .2779, p >.05; F (1, 4) = .6716, p >.05, respectively).

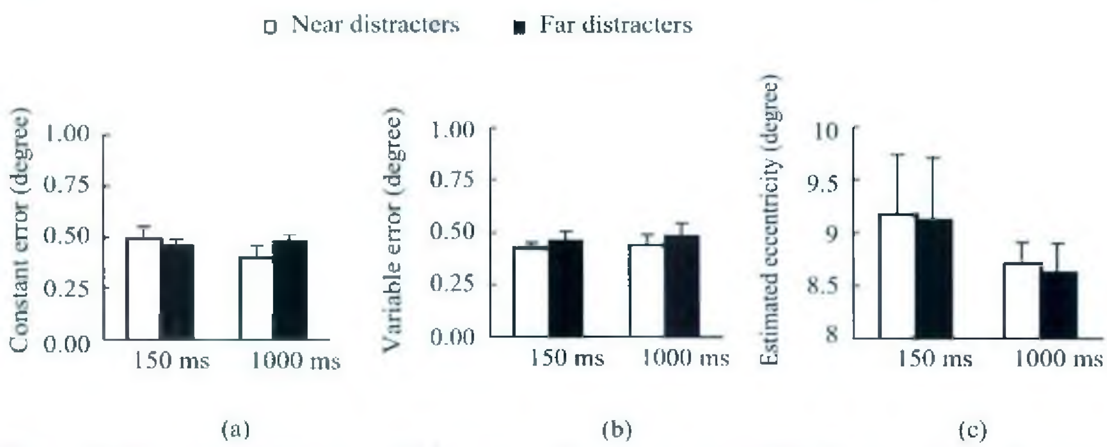


Figure 11: Mean constant error, variable error, and estimated eccentricity in near and far distracter conditions plotted as a function of exposure duration in (a), (b), and (c), respectively. The lower are the magnitudes of constant and variable errors the higher are the accuracy and precision, respectively. The smaller (larger) are the magnitudes of estimated eccentricity than actual eccentricity (here 9 degree) the larger are the foveal (peripheral) biases. Each vertical bar in panels (a) and (b) denotes ±1 standard error of the mean (S. E. M.) and that in the right panel denotes a ninety-five-percent confidence interval (95% CI).

Mean estimated eccentricities in near and far distracter conditions are plotted in Figure 11c as a function of exposure duration. A two way repeated measures ANOVA (2: near and far distracters × 2: 150 or 1000 ms exposure durations) revealed a non-significant main effect of near/far distracter (F (1, 4) = 2.763, p > .05) and a significant main effect of exposure duration (F (1, 4) = 8.752, p < .05). Interaction between the two variables was not significant (F (1, 4) = 0.135, p > .05). A 95% CI revealed that localization performance was unbiased with short durations but biased towards the fovea, regardless of the eccentricity of distracter, near or far.

8.4 Discussion

Results clearly ruled out the possibility that spatial remapping around distracters contributed to the reduction in foveal bias. In particular, there was no significant effect of eccentricity of distracters on the magnitude of foveal bias. On the other hand, as in Experiments 5 and 6, we showed that exposure duration affected foveal bias; reduction of foveal bias was observed only in short duration condition. This result again supported the idea that the origin of foveal bias is the attentional force at fixation. Even though we could not predict about precision, it was higher in near compared to far distracter conditions. This can be explained by the recent findings of Popple, Petrov, and Levi (2006) that the precision with which a pop-out target was localized within a sparse array was greater than within a dense array of Gabor patches. It is obvious that in Experiment 7 visual space would be narrower under near distracters than far distracters conditions. Hence, we speculate that higher precision in the former condition might be linked to the relatively dense array of visual space within which localization is done. We will discuss and interpret our results in greater detail in the following section.

Chapter 9: General Discussion

The present study examined visuospatial memory of human observers measuring constant, variable, and vector of errors in localization. The first experiment replicated the study of Adam et al. (1993) with the following modifications. It included relatively large target eccentricities ranging from 3-15 degrees. Also, the first experiment tried to hold the effect of cursor appearing position constant across conditions by placing it equidistant from the possible target locations. This control of cursor position was necessary since evidences are ample that cursor position confounds with target position. Unlike in Adam et al. (1993), we avoided using masks in all experiments since it has both facilitating and interfering effects on localization. The second, third, and fourth experiments were designed to dissociate attention-shift from memory-averaging as a mechanism modulating foveal bias. The last three experiments examined the mechanism underlying foveal bias. The results of all experiments are discussed and interpreted sequentially.

The main results of the first experiment were as follows: (i) constant errors were lowest in the 1000CF, highest in the 1000SF, and in-between in the 150CF condition, (ii) variable errors were lower in the 1000CF condition than in either of the other two conditions which themselves did not differ from each other, (iii) foveal bias was larger in the 1000SF than in either of the other two conditions which themselves did not differ from each other, (iv) constant, variable, and vector of errors did not change with target eccentricities and target directions in the 1000CF condition, (v) constant and variable errors in the 1000SF and 150CF conditions increased though nonlinearly with the increase of target eccentricities, (vi) constant and vector of errors in the 1000SF condition was larger at upper visual field than at lower visual filed at eccentricities exceeding 6 degree. The results are consistent with the predictions of the two-process model. These findings are interpreted and discussed in general discussion.

The superior performance in the 150CF and 1000CF conditions over the 1000SF condition provided further supporting evidence for the eye-movement system of the two-process model. However, one might question as to why performances were not comparable between 150CF and 1000CF conditions even though both conditions involved eye movements. One reason of the inferior performance in 150CF condition might be the due to temporal overlapping of the cursor onset and the saccade execution affecting final landing position of the eyes. This is highly likely to occur since saccade latency for 150 ms duration target was reportedly about 250 ms (Adam et al., 1993).

An alternative account for the differential performances in two saccade conditions might be due to nature of saccades. One assumption is that saccade in 150CF condition to be memory guided whereas in 1000CF condition to be visually guided. The basis of this assumption is as follows. Saccadic reaction time is no less than 200 ms in an overlap condition where the foveal fixation point remains visible during the appearance of the saccade target (Munoz, Broughton, Goldring, & Armstrong, 1998). Our experiment also employed overlapping paradigm and was participated by observers comparable to a section of age-group in the study of Munoz et al. (1998). Therefore, saccade onset in 150CF condition is not expected to be initiated before target offset. How observers then direct saccades to the invisible target location. The iconic memory or visible persistence (Coltheart, 1980) of a target that lasts about 150-300 ms following its offset (Di Lollo & Dixon, 1988) might have guided saccade in 150CF condition while aided in maintaining fixation on the target in 1000CF condition. This is particularly true for our experiment since we did not employ any backward masking stimulus that is assumed to disrupt visible persistence. Have memory guided saccades anything to do with the localization performance? Yes they do as literature suggested that memory guided saccades are usually less accurate than those in visually guided saccades due to both systematic and variable errors (Vergilino & Beauvillain, 2001). Therefore, performances are expected to be less than perfect in 150CF whereas perfect in 1000CF conditions. Our results are in complete agreement with this expectation.

The relatively high and stable accuracy and precision observed in the 1000CF condition can be explained again in terms of the higher accuracy and precision of the visually guided saccades. This finding leads us to accept the *final gaze hypothesis* as a valid postulate that asserts that the functional role of eye movements in localization performance is to provide the hand motor system with a spatial reference point defined in terms of the final gaze of the eyes; such an *external* mechanism would ensure a relatively stable and enduring representation of target location that would be relatively insensitive to decay. However, in order to verify final gaze hypothesis directly, it is inevitable to calculate the deviation of manual localization from the eye gaze direction after saccade. If final gaze hypothesis is correct, this deviation measures is expected to be the same between the 1000CF and 150CF conditions, since in both conditions, manual localization is based on the final gaze. As eye movement data were not gathered, analysis in that way is simply beyond our scope.

A question might be raised why conditions 150CF and 1000SF demonstrated comparable precision while differed in accuracy. Indeed, the above two conditions are not directly comparable due to the difference between them in exposure durations.

Mapp, Barbeito, Bedell, and Ono (1989) reported comparable accuracy and precision between saccade and no-saccade conditions for a target of 100 ms duration. Adam et al. (1993) have reported that accuracy increases with exposure durations in saccade condition alone. From these findings, we can educe that the eye movement system providing extra retinal signal improved accuracy in 150CF condition whereas poor spatial resolution associated with uncertainty of the target location equivalently impaired precision in both conditions. This latter assumption is well reflected in the gradual decrease in precision with the increase in eccentricities in 1000SF and 150CF conditions.

Finally, an upper lower visual field asymmetry observed in the 1000SF condition at eccentricities exceeding 6° is fairly compatible with the following findings. Genzano et al. (2001) have reported that observers were better at relocating stimuli presented in the lower than in the upper visual field. He et al. (1996) also reported superior performance in the lower visual field in search and tracking tasks attributing the phenomenon to higher attentional resolution in the lower visual field. The physiological basis of the asymmetry might be an asymmetric density in receptors and retinal ganglion cells between hemi-retina at eccentricities exceeding 6° (Curcio & Allen 1990).

On the whole, the findings were in general agreement with the two-process model. In addition, Experiment 1 added knowledge by demonstrating that precision was lower and bias was larger in attention condition. Moreover, under the condition where eye movement is allowed, localization performance assumed to be mediated by memory guided saccade for brief target is inferior to that mediated by visually guided saccade for long duration target. Furthermore, performance in visually guided saccade is not susceptible to be impaired with target eccentricity and target directions and, hence, highly accurate and precise.

The second set of three experiments explored the mechanism modulating foveal bias employing a spatial cueing paradigm. We placed landmarks peripheral to target and one of which was spatially cued by either flashing (Experiment 2) or by terminating from the display (Experiments 3, 4). We hypothesized that an abrupt change in landmark capturing observers' attention (for transient hypothesis, see recent contribution of Franconeri, Hollingworth, & Simons, 2005) would reduce foveal bias. The results of Experiment 2 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 3 showed that a sudden disappearance of the distracter, which seemed to create a unique transient, and hence captured observer's attention, significantly reduced foveal bias, suggesting that attention-shift, not memory-averaging, plays a key role in reducing foveal bias. The results of Experiment 4 provided firm evidence favoring attention hypothesis by newly showing that attention-shift not only attenuates but also accentuates foveal bias.

The results are partially consistent with previous reports that an additional element reduces foveal bias. For example, Sheth and Shimojo (2001) have demonstrated that a line near the target reduced foveal bias. On the contrary, 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. The landmark in our experiment was placed on a line passing through the target and fixation, a configuration congruent with the one reported to have reduced the frequency of foveal bias (Sheth & Shimojo, 2001). In contrast, the landmark in the study of Kerzel (2002b) was placed obliquely to the virtual line, and hence, could not affect foveal bias. These discrepant 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. Electrophysiological data also showed that visual processing was enhanced at the attended spatial location, and this facilitation of processing extended from the attended location to the point of fixation (Slotnick, Hopfinger, Klein, & Sutter, 2002). 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 Experiment 2, we found a SOA effect which had a similar time course as reported by Posner (1980). In Experiments 3 and 4, a prolonged SOA effect was observed, instead. The difference in SOA effect observed in present study 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 in Experiment 2 was a transient flash while that in Experiments 3 and 4 was a sustained disappearance until 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 2 and a non-significant SOA effect in Experiments 3 and 4.

Why was the attention-shift so effective in reducing foveal bias? Here, we speculate that some re-organization of visuospatial coordinates might have taken place around an attended salient distracter. As described in the introduction, foveal bias occurs even when observers are not provided with a fixation mark (Van der Heijden et al., 1999). This is interpreted as 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. In other words, attentional force at fixation is strengthened or weakened based on attentional capture by the abrupt appearance of salient features that in turn affects the binding between fixation and target. In other words, perhaps a vector summation of attention allocated at fixation, target, and non-target, determined the reproduced location of target.

One may contend that our results are due to 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.

The last three experiments examined the issue of attention in localization by manipulating spatial and temporal factors. The results of the three experiments were as follows: (i) accuracy was found independent of the presence or absence, invariance or variance, and nearness or farness of distracters, (ii) precision was greater in near than in far distracter conditions, (iii) localization was biased towards the fovea in the absence of distracters regardless of whether exposure duration was short or long, (iv) localization was unbiased in all distracter conditions with short exposure durations, and (iv) localization was biased towards the fovea in all but variant/ invariant distracter conditions with long exposure durations.

These results suggested a hypothetical idea that attentional allocation at fixation is reduced by the presence of target and non-targets when exposure duration is short. However, it would not be the case when exposure duration is long or when there is no non-targets. The strong attentional force at fixation is a requisite for foveal bias to occur. Consistent with our hypothesis, foveal bias was observed in all experiments under long exposure duration condition; also under short duration condition when non-targets were absent. The hypothesis can be supported by the report of Sheth and Shimojo (2001) that the magnitude of foveal bias increased with retention interval. From our results, we interpret the results in Sheth and Shimojo (2001) as due to the strong attentional force working at the fixation with increasing duration. Conversely, we found that the attentional force at fixation was weakened in short duration condition. That is, foveal bias was suppressed in the presence of distracters. This latter outcome is consistent with the findings that egocentric cues are suppressed by exocentric cues (Sheth & Shimojo, 2004, Lemay et al., 2004). In fact, the origin of suppression again is due to the reduced attentional force operative at fixation that attracts target.

Surprisingly, additional distracters in Experiment 5 reduced foveal bias but did not reduce constant and variable error even when stimuli were presented briefly. If location information availability was relevant to our results, then a significant rise in accuracy or precision would have been observed. Indeed, we found no such effects. On the other hand, foveal bias in the presence of distracters was significantly reduced with short exposure durations compared to long exposure durations. These results appeared to suggest that the role of non-targets was to alter the relative strength of attention at fixation and target which relies on temporal factors.

An alternative explanation can be found from the study of Musseler and van der Heijden (2004). They examined a model that postulates that in calculation of perceived positions two sources are involved, a sensory map and a motor map. Localization was reportedly unbiased in conditions where the sensory map could be used but biased in conditions where motor map had to be used. The experimental condition in which we simultaneously presented target and non-targets for a short time is comparable to that of Musseler and van der Heijden (2004) in which they claimed a sensory map was used.

Chapter 10: Summary and Conclusion

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Summary

The present study dealt with visuospatial memory of human observers. The first experiment compared between attention and saccade conditions. The results showed larger errors consistently on all parameters in attention condition. Of particularly interesting finding was that, in addition to attention condition, localization was biased towards fovea in saccade to brief target condition whereas unbiased in saccade to long duration target condition. This led us to presume that the origin of foveal bias might be attentional force at fixation. In the second, third, and fourth experiments, we examined the mechanism modulating foveal bias by spatially cueing an object adjacent to the target under attention condition. We found strong evidence that attention-shift affects foveal bias. This is congruent with our speculation that the points of regard in localization are the point of attention. The last three experiments examined the role of non-targets in localization. The results showed that localization was unbiased in short duration condition when target was simultaneously presented amidst non-targets. These results provided further evidence that attentional allocation at fixation and at target determined the magnitude and direction of error.

Conclusion

Localization can be well accounted if we take two factors, point of fixation and point of attention, into account. That is to say, the point of fixation and the point of attention can determine the direction and magnitude of error in localization. The vector of error is given priority over constant and variable errors in this current view. The reason is that the former is found sensitive to different conditions while the latter parameters are not, at least in our present study. This priority is further enhanced by the dearth of previous studies not considering all parameters simultaneously.

Now I would like to elaborate my initial point regarding fixation and attention. The two-process model of Adam et al. (1993) asserts that abrupt onset of target draws attention providing coarse location information followed by saccade providing fine location information. In my view, the saccade is necessary as an intermediate process and not crucial in final judgment. For fine location information, post saccadic attention and fixation are crucial. That means the point of attention following saccade (s) interacts with the point of fixation, at least at the time of encoding target location to determine reproduced location. Ample evidences supporting this view are available in the literature where mislocalization is explained by a saccade-contingent attention (e. g., Honda, 1999).To explain this point, let me give an example in which observers fixate at a point and a target appears peripherally. If saccade is allowed then observers will move eyes to the target. After saccade landing if fixation is maintained there and attention is apart, then localization will not be unbiased, rather biased towards other point of regard. This other point of regard is the point of attention which Fuchs (1938) termed pseudo fovea. On the other hand, van der Heijden et al. (1999) demonstrated that the point of fixation (not the fixation point) affects, at least in part, judged target position. Hubbard and Ruppel (1999) also argued that cursor position and fixation point may have been used as references for location judgments, resulting in landmark attraction or memory-averaging. Indeed, arguments of Hubbard and Ruppel (1999) can be interpreted as that the direction of localization is determined by the point of attention (here cursor position) that coincides with the point of fixation. Taken together, it stands that the origin of bias in localization is determined by the two factors, one is the point of attention and the other is the point of fixation.

How this proposed two-factor model can explain the results of present and previous studies. Let's take Experiment 1 of our study as a case where localization in 1000CF condition was unbiased which conflicts with previous findings that localization is biased towards fovea (e. g. Mateeff & Gourevich, 1983, 1984). However, it fits well with our model. If observers in 1000CF condition maintained fixation, as instructed, at the saccade landing position and their attention was allocated to that position, no bias in localization is expected, or in other words, localization would be completely biased towards the point of fixation. We, indeed, found this outcome. Why did then previous researchers find foveal bias in the similar condition? The reasons might be that, either the point of attention after saccade (i. e., post saccadic attention) did not correspond to the point of fixation at saccade landing position or they corresponded but the saccade landing position, and hence, point of fixation, was not on the target position. The latter account is again attributable to pre-saccadic attentional error that led saccade to a different position from the target and, hence, a different point of fixation.

On the other hand, in 1000SF condition (i. e., steady fixation or attention condition for a target of 1000 ms duration in which saccade was not allowed) localization was biased towards fovea which can be ascribed to the fact that attention and fixation did not correspond spatiotemporally. Because under that condition, observers had to simultaneously, as instructed, allocate attention to the fixation and to the target. Thus, a vector summation of attentional force determined the reproduced location. It is obvious that in 1000SF condition, localization will be biased towards fixation because attentional force at fixation would be stronger in that it is attended. However, this would not always be the case. Consider a situation where observers fixated at a point, a target appears at other location, and another object appears at a different location around the target appearing time. What would be the outcome in such a situation? According to our model, target would be displaced simply towards the resultant attentional force. There are evidences that the observers could not shift attention away from fixation to an extrafoveal position as efficiently as they could maintain attention at fixation (Sarrinen, 1993). Also, it was reported that when a fixation stimulus appeared continuously even after target presentation, the remote distracter effect decreased (e. g., Honda, 2005). These suggest that, owing to relatively strong attentional force at fixation, localization would be predominantly biased towards fixation. However, if distracter captures attention strongly then the outcome might revert, that is localization would be biased towards distracter and what we exactly found in our Experiments 2, 3, and 4. It is noteworthy that attention drawn by additional object has a spatial range which in our experiment was 3 degree from the target (for a similar report, see also Deubel, 2004). Thus, two factors, one is the point of fixation or fovea, and the other is the point of attention or pseudo fovea which are in the core of the proposed model can explain localization well.

The proposed model is not beyond limitations, however. The immediate limitations arise from the methodology of the experiments upon which the model is based. For example, the experiments did not systematically manipulate magnitude of attention and point of fixation. Another technical limitation is that the point of fixation even though can be determined by eye-movement recording, the point of attention seems difficult to be determined, and hence, verification of the proposed model deemed difficult. Further, the model needs to be verified under certain circumstances, for example, where check for the compatibility of the model with the role of disparity, vergence, and accommodation is possible, to increase its robustness and generality.

Further, how the model will explain the phenomenon concerning the asymmetric dispersion of localization responses attributed to the heterogeneous spread of attention across visual fields (Tsal & Barcket, 1999, 2005) should also be a matter of future concern. Therefore, it is formidable to address these issues in future research.

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