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Uddin, Muhammad Kamal
Faculty of human-environment studies, Kyushu university

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Visual spatial localization and the two-process model

Muhammad Kamal Uddin[1] (*Faculty of human-environment studies, Kyushu university*)

This review paper begins with a brief history of research on localization followed by its definition and classification. It also presents important parameters of localization and factors that affect localization. The paper gives an overview of the two-process model and highlights its limitations. A careful review exposed inadequacies in the model in particular and in localization research in general warranting a clear need for further investigations. Here the author reports findings of his seven experiments and, based on them, proposes a model. According to the proposed model, two factors, one is the point of fixation or 'fovea' and the other is the point of attention or 'pseudo fovea', together determine the vector of error in localization.

Keywords: fovea, pseudo fovea, saccade, vector of error, localization

1. A brief history of object localization research

Identity and location are two fundamental aspects of object vision that could not be completely dissociated yet. In the late sixties of the twentieth century 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, 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 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 opeartes in two sequentially arranged stages in which the opeartion 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 unit time 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 integreation 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 signalling where it is. To localize a feature in the visual field the involvemnt 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

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even simple visual features requires the allocation of attentional resources. The preattentive stage is capable to detect feature differences or discontinuties 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 virtually 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 to formulate a reliable theory on either localization or identification.

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

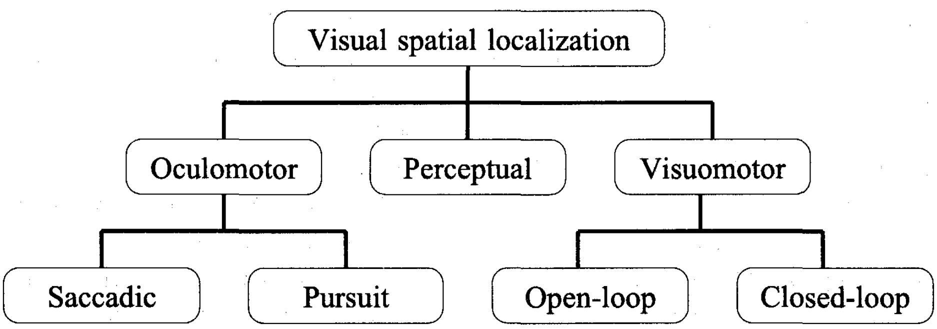

Fig.1 Diagram depicting different types of visual spatial localization.

readers interested in the area, the author hereby presents a simplified classification of localization in the following diagram (Fig. 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.

3. Oculomotor localization

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.

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.

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.

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.

6. Parameters of localization

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

0.1.1 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:

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

0.1.2 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.

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

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

0.1.3 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).

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

The above equation in effect can not manifest the direction of error. So, the author adopted 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 foveofugal/central or foveopetal/peripheral directions and as such is not a genuine vector of mathematics.

Vector of error = Estimated eccentricity — Actual eccentricity

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

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 i[th] response position, Y_i the Y coordinate of i[th] response position, X_0 the X co-ordinate of fixation mark, and Y_0 the Y co-ordinate of fixation mark.

7. Factors affecting localization

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 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.

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, 1977; 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.

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.

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 25×19 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.

9. The 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 limited to 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 big defect with the two-process model is that it asserts unbiased or fine localization in saccade condition. In fact, saccade is a necessary condition but not sufficient condition for accurate localization. For accurate localization, post-saccadic attention is needed, especially in manual localization. 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). The authors 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, the two-process model does not seem to predict such phenomena.

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 search on this important topic in human visuomotor behavior".

10. The proposed model

The proposed model is based on findings of the author's seven experiments that examined visuospatial memory in relation to attention. The first experiment (Uddin, Ninose, & Nakamizo, 2004) compared between attention and saccade conditions. The results showed larger errors 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 attention and fixation. We examined this issue in subsequent experiments. In the second, third, (Uddin, Kawabe, & Nakamizo, 2005a) 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 which is congruent with our speculation that the point of attention and the point of fixation jointly determines the direction of localization bias. The last three experiments (Uddin, Kawabe, & Nakamizo, 2005b) 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 firm evidence that attentional allocation to point of fixation and to target location determined directionality.

Thus, the author here proposes that the direction and magnitude of bias in localization can be well accounted if two factors, fixation and attention, are taken into account. That is to say, point of fixation and point of attention, together can determine the vector of error in localization. The vector of error is given priority as a parameter 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 total absence of not considering all parameters simultaneously in any previous studies.

Now, the author likes to elaborate his initial point concerning 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 his view, the saccade is necessary as an intermediate process but for final judgment it is of no use. Rather, post saccadic attention and point of fixation are crucial for localization. That means, attention that follows saccade interacts with the fixation to determine the vector. Ample evidences supporting this view are available in the literature where mislocalization is explained by a saccade-contingent attention (e. g., Honda, 1999). To elaborate this point, let him give an example in which observers fixate at a certain point and a target appears apart from it peripherally. If saccade is allowed then observers will move eyes to the target location. If fixation after saccade is maintained at target location and attention is apart, then localization will not be unbiased as due to absence of correspondence. Instead, localization will be biased towards point of attention which Fuchs (1938) referred as 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) argued that cursor position and fixation point may have been used as references for location judgments in their experiments, resulting in landmark attraction or memory averaging. Indeed, the later arguments can be interpreted as that the direction and magnitude of localization error is determined by the point of attention (drawn by cursor) that coincides with the point of fixation. Taken together, it stands that the origin of bias in localization is jointly 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 be reconciled with the results of present and previous studies. Let's take Experiment 1 (Uddin et al., 2004) as a case where localization was unbiased in 1000 CF condition (changing fixation or saccade condition for a target of 1000 ms duration) which are in conflicts with previous findings that localization is biased towards fovea (e. g. Mateeff & Gourevich, 1983, 1984). However, it can be interpreted by the proposed model. If observers in 1000 CF condition maintained, as instructed, fixation 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 where attention is allocated. The authors, indeed, found this outcome. Why then previous researchers found foveal bias in the similar condition. The reasons might be that, either the point of attention after saccade 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. This latter account is again attributable to attentional error that led saccade landing position to a different position than the target and, hence, different point of fixation than the target position.

On the other hand, in 1000 SF condition (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 explained as that attention and fixation did not correspond spatially since under this condition observers had to simultaneously, as instructed, allocate attention to the fixation and to the target. Thus, a vector summation of attentional force is taken place that determined the direction and magnitude of bias. It is obvious that in 1000 SF condition, localization will be biased towards fixation because attentional force would be stronger at fixation if 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 the proposed model, target would be displaced towards the resultant attentional force, with a priority at the point of fixation since there is evidence that when a fixation stimulus was continuously presented even after target presentation, the remote distracter effect decreased (Honda, 2005). This means, attentional force at the location of other object is reduced by fixation point. However, if other object captures attention strongly then the outcome might revert, that is localization would be biased towards that object. It is also likely that localization would not be biased towards fixation or towards other object, rather remain unbiased. In our Experiments 2, 3, and 4 we found results consistent with our expectation; foveal bias diminished and peripheral bias observed as the distance of additional object approached closest to the target with respect to fixation. It is noteworthy that the point of attention drawn by additional object has a spatial range demonstrated in our experiment as 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 appear necessary and sufficient to explain vector of error in localization.

However, the proposed model is not beyond limitations. 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 limitation with our model is that the point of fixation even though can be determined by eye-movement recording, the point of attention seems difficult to be determined. The proposed 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 & Bareket, 1999, 2005) should also be a matter of future concern. Therefore, it is formidable to address these issues carefully in future research.

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