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ACCURACY AND PRECISION OF SPATIAL LOCALIZATION WITH AND WITHOUT SACCADIC EYE MOVEMENTS: A TEST OF THE TWO-PROCESS MODEL

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We tested the two-process model of spatial localization (Adam, Ketelaars, Kingma, & Hoek, 1993) by measuring accuracy and precision of localization performance in three stimulus conditions: (i) *no-saccade* — observers were to maintain gaze on the fixation mark while target appeared for 1 s, (ii) *saccade to on-target* — they had to quickly saccade to and fixate on target remaining on for 1 s, and (iii) *saccade to off-target* — they had to quickly saccade to the target appeared for 150 ms. Observers' task was to adjust position of a mouse cursor manually so that its position corresponds to the perceived position of the target. Results with six observers are consistent with the model suggesting localization performance to be mediated by memory-guided saccade for brief target and visually guided saccade for long duration target. The results further suggest that the memory-guided saccade provides relatively less accurate and precise information for localization and is a function of target eccentricity.

Key words: spatial localization, two-process model, memory-guided saccade, visually guided saccade

Adam, Ketelaars, Kingma, and Hoek (1993) reported on the time course and accuracy of spatial localization in which they demonstrated that localization performance showed an initial steep rise during the first 50 ms of stimulus duration followed by a gradual rise after 50 ms, reaching maximal performance at about 300 ms. They interpreted these two localization performance functions by the two-process model, which states that the two systems, namely the attention system for the initial steep rise and the eye movement system for the subsequent gradual rise, operate sequentially.

The two process-model was supported by Adam et al. (1993) in which localization

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performance was measured in two conditions: one condition in which observers were allowed to make eye movements, and the other in which observers were not allowed to make eye movements. In the latter condition observers were instructed to maintain fixation on the fixation mark. Results demonstrated that, with or without eye movements, localization performance showed the same rapid improvement over the first 50 ms of stimulus duration, whereas thereafter localization accuracy markedly improved in the *eye movement* condition but not in the *no-eye movement* condition. The first finding, combined with evidence that the time needed to shift attention is in the order of 50–60 ms (Adam, Huys, van Loon, Kingma, & Paas, 2000), accords with the notion that the attention system is involved in localizing very short duration stimuli. The latter outcome underscores the critical importance of the eye movement system for accurate localization performance.

According to the model, higher accuracy in performance is predicted in the *saccade* condition than that in the *no-saccade* condition. The model explicitly emphasizes the importance of eye position information for the higher performance; however, it does not depict the reason explicitly as to why performance should gradually improve in saccade condition reaching peak at target duration of about 300 ms. We hereby propose that localization in the saccade condition to be mediated by memory-guided saccade system for brief target and visually guided saccade system for long duration target.

The purpose of this study was to provide further evidence for (or against) the model by measuring accuracy and precision of localization performance in three conditions: (i) *no-saccade*, (ii) *saccade to on-target*, and (iii) *saccade to off-target*. The model predicts that the higher performance would be obtained in the *saccade to on-target* and *saccade to off-target* conditions than in the *no-saccade* condition. Direct comparison between the *saccade to on-target* and *saccade to off-target* conditions would elucidate the effects of visually guided saccade and memory-guided saccade on spatial localization performance.

METHOD

Observers:

Six graduate students — three females and three males including the first author — of Psychology at 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 naïve as to the purpose of the experiment and extensively experienced in psychophysical experiments.

Apparatus and Stimuli:

Stimuli were presented on a 40.5 cm × 30.5 cm color CRT monitor (IIYAMA HM204D) having pixel resolution of 1024 × 768 and refresh rate 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 *no-saccade* 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.,

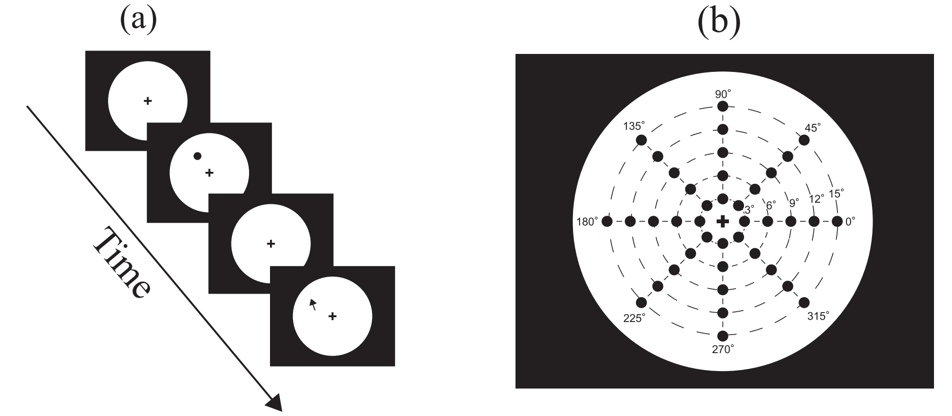

Fig. 1. Schematic representations of (a) the stimulus sequence, where the cross is the fixation mark, the black dot is a target, and the arrow is a mouse cursor, and (b) target locations presented.

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.

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" the experimenter pressed space key that initiated the target to have appeared randomly at one of the 40 possible locations comprising 5 target eccentricities in visual angles — 3°, 6°, 9°, 12°, and 15° and 8 target directions in polar angles — 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°; 0° being at right horizontal axis and moving counterclockwise. The mouse cursor appeared after a fixed interval of 150 ms following target offset at one of the eight random locations (same as target directions in polar angles). It appeared 3° away from target and disappeared after a trial is over (see Fig. 1 for schematic of procedures and target locations). Thus, the effect on perceptual localization of cursor position is minimized and held constant throughout all possible combinations of conditions by making it appear at equidistant position around the target. Three stimulus conditions were employed: (a) *no-saccade* — observers were instructed to maintain gaze steadily at the fixation mark while target appeared for 1 s, (b) *saccade to on-target* — observers were instructed to quickly saccade to and fixate on target that appeared for 1 s, and (c) *saccade to off-target* — they were instructed to quickly saccade to the target appeared for 150 ms. In all stimulus conditions, observers' task was to place the cursor to the perceived location of the offset target 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, observers had to maintain fixation on the always-visible fixation mark. A total of 16 training trials preceded experimental trials in the *no-saccade condition* so that observers acquire abilities 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 2nd and 3rd replication. Order of stimulus conditions followed a partially Latin square design and the experiment followed a totally within-subject three-factor (stimulus conditions, target eccentricities, and target directions) design with 6 replications. Each observer thus performed a total of $3 \times 5 \times 8 \times 6 = 720$ trials.

Basic Data:

We first calculated the mean response position from six trials of each observer. 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 error, the higher was the accuracy and precision of localization, respectively. The constant- and variable errors obtained, were for 40 locations per observer and the unit of measurement in all cases was of degree in visual angle. Constant and variable errors can be expressed symbolically as follows:

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

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

Where,

$\bar{X}$=X position of mean response, $\bar{Y}$=Y position of mean response,
X=X position of target, Y=Y position of target,
X_i=X position of ith replication, Y_i=Y position of ith replication.

Data Analysis:

Data were subjected to three-way repeated measures ANOVA. To provide a more detailed analysis, additional two-way repeated measures ANOVAs were carried out for each stimulus condition separately.

RESULTS

Constant Error of Localization

Constant error of localization for each stimulus condition is shown as a function of target eccentricities (Fig. 2a) and target directions (Fig. 2b). A three-way (3 stimulus conditions×5 target eccentricities×8 target directions) repeated measures ANOVA yielded significant main effects of stimulus conditions, $F(2, 10)=29.985$, $p<.01$; target eccentricities, $F(4, 20)=9.226$, $p<.01$; target directions, $F(7, 35)=7.615$, $p<.01$; significant interaction between stimulus conditions and target eccentricities, $F(8, 40)=2.954$, $p<.01$, stimulus conditions and target directions, $F(14, 70)=4.564$, $p<.01$, and target eccentricities and target directions, $F(28, 140)=1.876$, $p<.01$. Post hoc pair-wise comparisons (Ryan's method, $p<.05$) showed significant difference between all possible pairs of stimulus conditions; the highest accuracy in the *saccade to on-target* condition followed by that in the *saccade to off-target* condition and the lowest being in the *no-saccade* condition. Furthermore, ANOVA performed for each stimulus condition separately showed an upper/lower asymmetry in *no-saccade* condition at the target eccentricity exceeding 6°. In the *saccade to on-target* condition, constant errors varied with neither target eccentricities nor target directions.

Variable Error of Localization

Variable error of localization for each stimulus condition is shown as a function of target eccentricities (Fig. 3a) and target directions (Fig. 3b). A three-way (3 stimulus conditions×5 target eccentricities×8 target directions) repeated measures ANOVA yielded significant main effects of stimulus conditions, $F(2, 10)=235.071$, $p<.01$; 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 *saccade to on-target* condition was significantly more precise than in either of the other two conditions. Furthermore, ANOVA performed for each stimulus

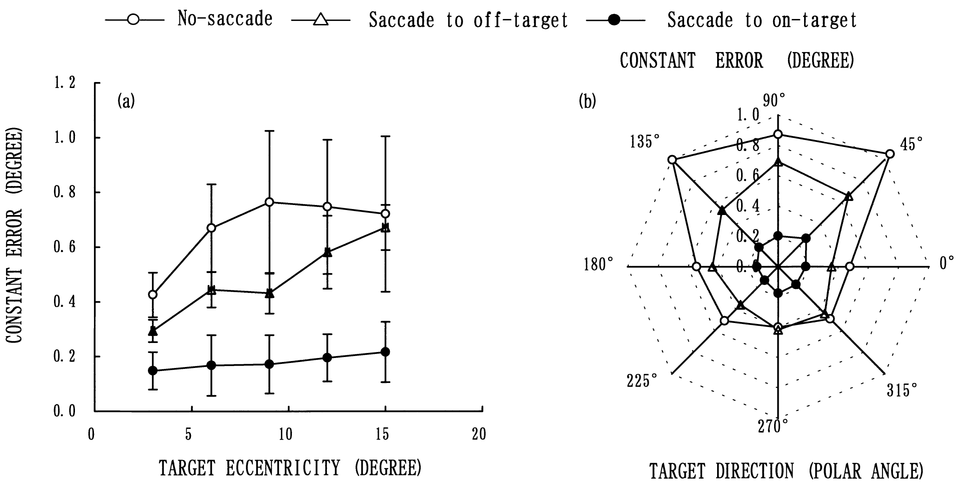

Fig. 2. Constant error (distance of mean response position from respective target location) as a function of (a) target eccentricities and (b) target directions. Each datum point in (a) and (b) is the average from 48 (6 observers×8 directions) and 30 (6 observers×5 eccentricities) measurements, respectively. Vertical bars in (a) denote ±1 standard error of mean and values along vertical axis in (b) are the radii of dashed circles to represent the magnitude of constant error.

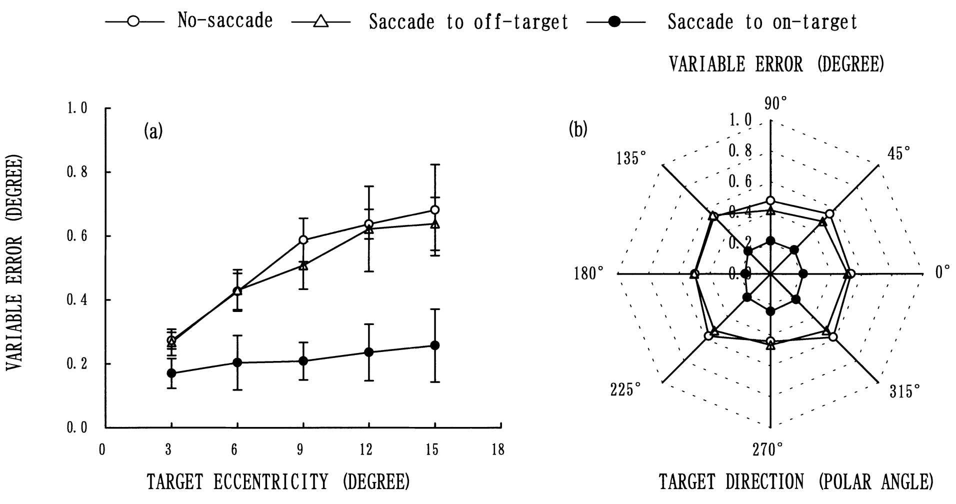

Fig. 3. Variable error (Mean deviation of responses from their respective mean position) as a function of (a) target eccentricities and (b) target directions. Each datum point in (a) and (b) is the average from 48 (6 observers×8 directions) and 30 (6 observers×5 eccentricities) measurements, respectively. Vertical bars in (a) denote ±1 standard error of mean and values along vertical axis in (b) are the radii of dashed circles to represent the magnitude of variable error.

condition separately showed that variable errors increased with the increase of target eccentricities in *saccade to off-target* and *no-saccade* conditions and remain unchanged in *saccade to on-target* condition.

DISCUSSION

The main results of the present experiment were as follows: (i) the accuracy and precision in the *saccade to on-target* condition was higher than that in the *saccade to off-target* and *no-saccade* conditions, (ii) neither accuracy nor precision in the *saccade to on-target* condition did vary statistically with target eccentricities and target directions, (iii) the *saccade to off-target* condition was statistically better than and same as the *no-saccade* condition in terms of accuracy and precision, respectively, (iv) both accuracy and precision decreased with the increase of target eccentricities in the *saccade to off-target* condition, and (v) an upper/lower asymmetry in accuracy was observed in the *no-saccade* condition. These findings are interpreted and discussed sequentially as follows.

Firstly, the higher accuracy and precision in the *saccade to on-target* condition than in the *no-saccade* condition provided further supporting evidence for the eye movement system of the two-process model. The reason why performance in the *saccade to off-target* condition was not comparable to that in the *saccade to on-target* condition might be the likelihood of temporal overlapping of the onset of the cursor and the execution of saccade in the former condition. This temporal overlapping might have affected the final landing position of the eyes. However, this explanation is not tenable since saccade latency for target of 150 ms duration was ~250 ms as reported by Adam et al. (1993). The alternative account for the impaired performance in the *saccade to off-target* condition might be the fact that memory-guided saccades (i.e., saccades in *saccade to off-target* condition) are usually less accurate than those in visually guided saccades (i.e., saccades in the *saccade to on-target* condition), due to both systematic and variable errors (Vergilino & Beauvillain, 2001).

Secondly, relatively high and stable accuracy and precision observed in the *saccade to on-target* condition can be explained again in terms of the higher accuracy and precision of the visually guided saccades. This finding combined with the first finding can be taken 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 *saccade to on-target* and *saccade to off-target* conditions, since in both conditions, manual localization is based on the final gaze. Since we have no eye movement data, we hope to conduct future experiment to test the hypothesis directly. The second finding is partially at variance with the report of Adam, Paas, Ekering, and van Loon (1995) that accuracy decreases with the increase of target distances. This is true for brief targets, however, not justified for long duration target. The authors averaged localization performance over many different exposure durations and mistakenly expressed it as a function of target distance.

Thirdly, higher accuracy in the *saccade to off-target* condition than in *no-saccade* condition provides supporting evidence again for the superior role of *eye movement system* of the two-process model. Since iconic memory as reported by Di Lollo and Dixon (1988) lasts about 150–300 ms following stimulus termination, observers were able to saccade (though not precise) to the target while it was physically absent. The answer as to why the two conditions demonstrated the similar and relatively low precision lies in the fact that both conditions relied on the poor spatial resolution of the peripheral target and hence poor precision in localization.

Fourthly, the decrease of both accuracy and precision with the increase of target eccentricities in the *saccade to off-target* condition is an obvious outcome since spatial resolution of the peripheral retina decreases as a function of eccentricity. This declining resolution has reflected on the iconic memory available for shortly visible targets, which (iconic memory) is progressively distorted with eccentricity while being used in making saccades.

Finally, an upper/lower visual field asymmetry observed in the *no-saccade* condition at eccentricities exceeding 6° is fairly compatible with the following findings. Receptors and retinal ganglion cells are denser in the human upper than lower hemi-retina at eccentricities exceeding 6° (Curcio & Allen, 1990). This suggests that upper/lower asymmetry in receptors and retinal ganglion cell density has bearing on the upper/lower visual field asymmetry in localization accuracy. The asymmetry is also generally consistent with the findings reported by He, Cavanagh, and Intriligator (1996) that attentional resolution is greater in the lower than in the upper visual field.

On the whole, our findings are in agreement with the two-process model suggesting additionally that localization performance for brief target is mediated by *memory-guided saccade* and for long duration target by *visually guided saccade*. Moreover, performance mediated by *visually guided saccade* is not a function of target eccentricity and target direction and is highly accurate and precise as opposed to that by *memory-guided saccade*.

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