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Vision, Attention, and Action: Inhibition and Facilitation in Sensory-Motor Links Revealed by the Reaction Time and the Line Motion

Shinsuke Shimojo, Yasuto Tanaka, Okihide Hikosaka, and Satoru Miyauchi

ABSTRACT

To investigate critical factors for local inhibition and facilitation in visual-motor tasks, we randomized stimulus dimensions (location, color, and orientation) and response-stimulus interval across trials. The subject performed four different tasks. Reaction times at the same location were longer, that is, "inhibition of return" (IOR) occurred, in the detection and location discrimination tasks. Reaction times at the same location were shorter in the color and orientation discrimination tasks. IOR was observed also in arm-reaching and saccadic eye movement tasks. Moreover, the task-dependent difference of RTs was observed also with popout displays. The results indicate a dissociation of two visual functions: detection/orienting and fine feature analysis.

To investigate whether motor readiness could draw attention to the target location and have an influence on visual information processing, we employed the "line motion" illusion; we showed that mere preparation for a motor response, such as arm reaching or saccade, would be sufficient to yield local facilitation at the prepared target location.

In this chapter, we discuss issues related to functional links between the visual and the motor systems. For this purpose, we will present two sets of findings: one employing the reaction time paradigm and indicating functional segregation of two visual functions, and the other employing the "line motion" paradigm and indicating effects of motor readiness on the visual information processing.

23.1 REACTION TIME AND ATTENTION

Spatial attention is an indispensable aspect of visual information processing: indispensable because the brain has a limited capacity, whereas the constant flows of sensory inputs could be infinite in theory. Without selection and filtering by attention, it would be impossible to perceive what is important and to respond to it appropriately (James 1890; Helmholtz 1910; Broadbent 1958). On the other hand, some authors have recently argued that there is no limit to the brain's capacity for visual information processing (Van der Heijden 1991). Limited capacity may, instead, concern "selection for action." This view of spatial attention may be a part of the reason why reaction time (RT) has been often employed as a sensitive measure to access the selection

and filtering processes, and it has revealed various effects in a spatiotemporal context.

For instance, consider a situation where a cue and a target are presented sequentially, either at the same or different locations. When the target is presented at the same location as the cue, RT is larger than that at a different location. This is so particularly when the interval between the onset of the cue and the target (stimulus onset asynchrony, or SOA) is relatively large (300–1500 ms; Posner and Cohen 1984). This has been called “inhibition of return” (IOR) and repeatedly duplicated (Maylor 1985; Nissen 1985; Kwak and Egeth 1992; Tassinari et al. 1994; Gibson and Egeth 1994; Tip et al. 1994).¹

2.3.2 INHIBITION OF RETURN AND ITS UNDERLYING MECHANISM

The underlying mechanism of IOR is unknown, however. Because the reaction task involves various levels of processing, it is unclear at which level the effect occurs.² Some researchers suggest that inhibition occurs when the location of the target alone is changed (Kwak and Egeth 1992), that IOR is therefore closely related to spatial location, rather than to any other visual attributes of the target (Nissen 1985; Kwak and Egeth 1992). They argue that this effect occurs in the visual orienting process, for which a “spotlight” would be a good metaphor (Posner 1980). Meanwhile, others suggest that facilitation instead of inhibition, may occur in the different conditions or tasks (Ter Valdes, and Neill 1994).

To understand the mechanisms more inclusively, we first tried to duplicate the inhibitory effect in a simple detection task, which was similar to that employed by Kwak and Egeth (1992).

A Pilot Study

A single target was presented in either the top left or top right position of the display, while the subject fixated at a point (FP) in the bottom center. The location of the target was randomized between these two locations across trials. The interval between the button-pushing response and the next target appearance (reaction stimulus interval, or RSI) was also randomized across trials (200/400/1,000/2,000 ms). The distance between the target and FP was 12 degrees. Note that there was no cue in this experiment, and we were mostly interested in the positional effect of the previous target on RT to the present target. Four subjects (two naive and two nonnaive (authors)) were asked to detect a target, and to press a mouse button as quickly as possible.

In results, strong inhibition of return was obtained for all subjects at all RSIs, except the longest (2,000 ms). Thus the cue/target distinction is not a necessary condition for IOR, as originally suggested by Tassinari and his colleagues (Tassinari et al. 1987).

23.3 TASK DEPENDENCY OF INHIBITION AND FACILITATION

What are the critical conditions for the IOR effect, then? Could the distinction between detection and discrimination be critical? Or rather, could the type of visual information, say, spatial versus nonspatial attributes be critical (Kwak and Egeth 1992; Tassinari et al. 1994; Terry, Valdes, and Neill 1994)? To address these issues, we conducted experiment 1.1.

Experiment 1.1: Task Dependency of Inhibition and Facilitation of Return in Button Pressing

Subjects Six subjects participated in the experiment: four naive and two nonnaive (authors).

Stimuli and Apparatus Stimulus configuration was similar to that employed in the pilot study; as in the pilot study, there was no cue. Location (left/right), color (red/green), and orientation of the target (vertically/horizontally elongated) were all randomized across trials (see fig. 23.1).

The stimuli were presented on the CRT display, controlled by a personal computer (Commodore Amiga 500). Target size was 0.5 degree \times 0.4 degree, and its luminance was 6.4 cd/m² (hue: red (.555, .344); green (.320, .555)). The fixation point's size was 0.4° \times 0.4°. Luminance of the background was 0.01 cd/m². The distance between the fixation point and the target was 6.0 degrees. Viewing distance was 114 cm. Subject's head was

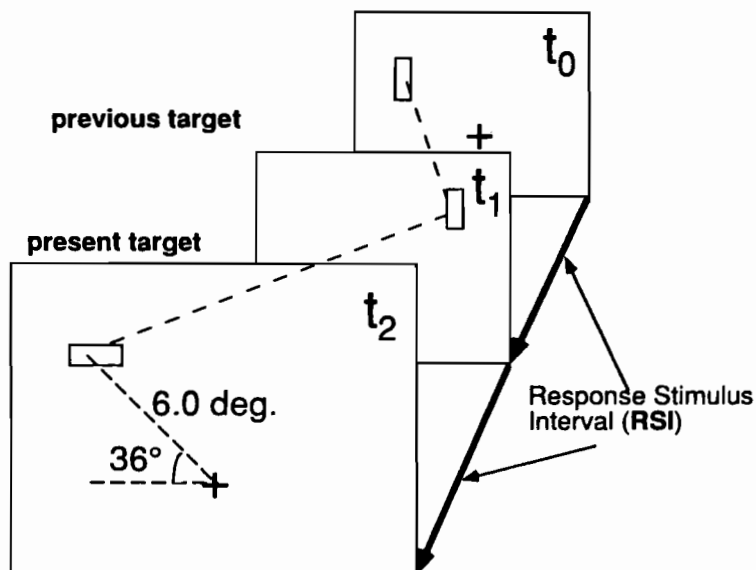


Figure 23.1 Stimulus configuration and sequence for RT experiment with single target (experiment 1.1).

fixed by the chin rest. Eye fixation was monitored in selected experiments using the *Ober2* system (Permobil Corp.; see the stimuli and apparatus section of experiment 1.3 for more details). The experiment was conducted in a completely dark room.

Procedure The stimulus sequence is illustrated in figure 23.1. Subjects were asked to fixate on the fixation point all through the session, and to press a mouse button in response to each target presentation. Each of the subjects was engaged in four tasks in separate sessions: (1) simple detection; (2) location discrimination (left/right); (3) color discrimination (red/green); and (4) orientation discrimination (vertical/horizontal). The order of these sessions was randomized across subjects. RSI was also randomized (100/300/500/1,200 ms). Note that the stimuli and their sequence were identical across all the tasks. The subject made two-alternative forced-choice (2AFC) judgments by button pushing for all the tasks, except the simple detection task. Thus the only difference was the nature of the task.

Subjects performed a practice session (100 trials) before each session of the experiment; the total number of trials was 300 in each experimental session. We analyzed data based on the positional relationship between the previous and the present trials. RTs in error trials were eliminated from the data analysis. Sessions where the error rate for discrimination exceeded 10 percent were considered unreliable and eliminated.

Results The results were fairly straightforward. IOR was obvious, that is, RT at the *same* location was *longer*, in the simple detection and the location discrimination tasks (see fig. 23.2, top). The opposite pattern of results, however, was found in the color and the orientation discrimination tasks; RT at the *same* location as in the previous trials was *shorter* than that at the different location (see fig. 23.2, bottom). We call this effect "facilitation of return" (FOR). The consistency of results across six subjects is obvious in table 23.1. We also pooled the data across the subjects and applied a four-way repeated-measures ANOVA (RSI \times location \times color \times orientation). The results can be summarized as follows: (1) for the detection task, location ($p < .01$), orientation ($p < .01$), RSI ($p < .01$) and location \times RSI ($p < .05$) factors were statistically significant; (2) for the location discrimination task, location and color \times orientation factors were significant (both $p < .01$); (3) for the color discrimination task, location, color, location \times color, and color \times orientation factors were significant (all $p < .01$); and (4) for the orientation discrimination task, location ($p < .05$), location \times orientation ($p < .01$), and color \times RSI ($p < .05$) factors were significant.

Discussion The opposite polarity of results between the two groups of tasks should be attributed to the task difference per se because the stimulus parameters and the responses were identical. However, it was not the distinc-

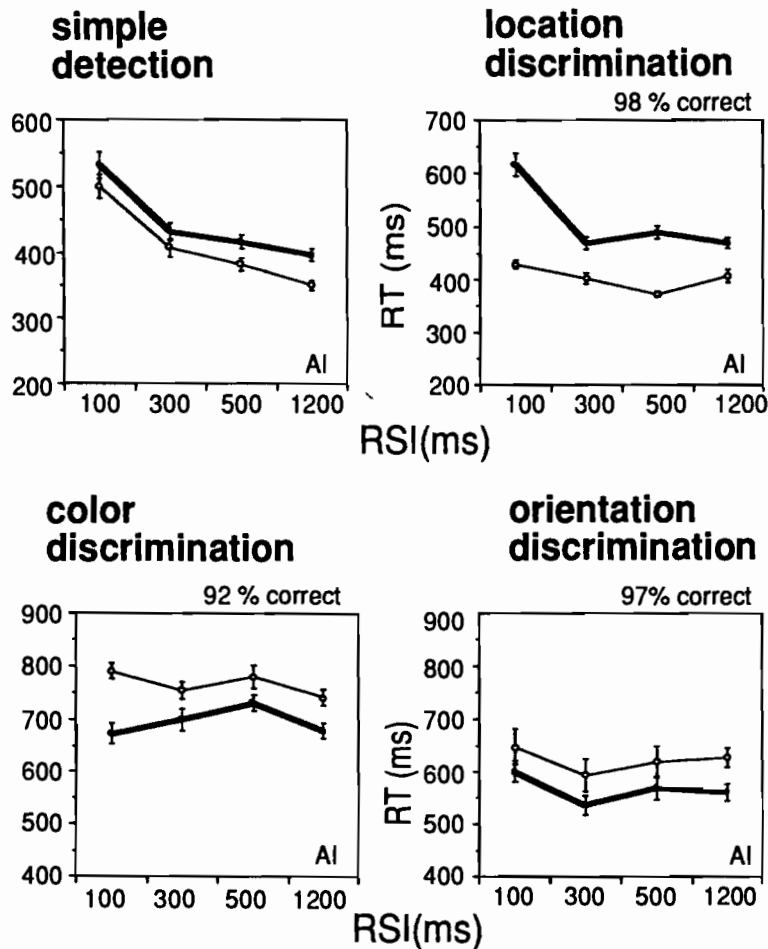


Figure 23.2 RT as function of RSI in single-target experiment (experiment 1.1). Results in four different tasks are shown separately in separate panels. Bold line indicates RT at same location, and thin line indicates RT at different location. Vertical bars show standard errors.

tion between detection and discrimination, but rather what information is necessary to perform the task, that seemed to be critical. On one hand, there were tasks that essentially require, or at least trigger, spatial orienting (detection and location discrimination), where we consistently found inhibition of return. On the other hand, there were tasks that require feature analysis (color and orientation discrimination), where we consistently found facilitation of return. The FOR is no doubt reminiscent of the benefits usually obtained with valid cues (e.g., Posner 1980). The critical difference, however, is that in our experiment there is no cue/target distinction, and no valid/invalid distinction either. That is, the kind of facilitation reported here is nothing to do with "informative" cues. The relationship of our findings to the facilitatory repetition effects reported by Pashler and Baylis (1991) and Maljkovic and Nakayama (1994) should be investigated in future.

Table 23.1 Summary of Results in Single-Target Experiment (Experiment 1.1)

Subjects	Orienting tasks		Feature tasks	
	Simple Detection	Location Discrim.	Color Discrim.	Orientation Discrim.
YT	-**	-**	+**	+**
SS	-**	-**	+**	+**
KS	-**	-**	+**	+**
AM	-**	-**	+**	ns
AI	-**	-**	+**	+**
SP	-**	-**	+**	+*

Note: Subjects YT and SS were nonnaive, while the others were naive. The data were analyzed by ANOVA. The IOR is indicated by -, whereas the FOR is indicated by + symbols. Data were analyzed by ANOVA for statistical significance, as indicated by * and **.

23.4 GLOBAL ORIENTING VERSUS LOCAL FEATURE: THE CASE OF VERNIER TASK

The dichotomy is still ambiguous because spatial information could be used both for global orienting and elaborate analysis of object features. The question is whether the *global* spatial information is critical, or whatever is *spatial* is critical even at the finest scale, for IOR to occur. To answer this question, we next employed a vernier discrimination task.

Experiment 1.2: Vernier Task

Subjects Four subjects participated in the experiment: two naive and two nonnaive (the authors).

Stimuli and Apparatus The stimulus configuration and sequence and the apparatus were similar to those employed in experiment 1.1, except that this time the target consisted of two horizontal line segments and one dot located either above or below these reference lines (see fig. 23.3). The size of each line was 0.22 degree \times 0.10 degree, and the dot size was 0.07 degree \times 0.10 degree. The distance of the two lines was 0.22 degree, and the distance between the dot and the reference line was 0.10 degree. The distance between the two possible target locations was 20.2 degrees, and the distance between the fixation point and the target was 12.5 degrees. The viewing distance was 57 cm. The experiment was conducted in a completely dark room.

Procedure Subjects were asked to fixate on the fixation point all through the experimental session, and to make a 2AFC judgment as to whether the target dot was above or below the reference lines (We found this task

particularly revealing because it required spatial information just as in the location discrimination, yet it was a typical task of elaborate feature analysis just as the color/orientation discrimination.) The stimulus (above/below), its location, and RSI were all randomized across trials. The data were analyzed primarily in terms of the positional relationship of the targets between the previous and the present trials.

Results and Discussion The results showed a clear facilitation of return (see fig. 23.3B), supporting the notion that fine shape discriminations lead to FOR, whereas global spatial orienting is necessary for IOR. A three-way repeated-measures ANOVA (RSI \times location \times feature) revealed only the main effect of location as significant ($p < .01$).

We have recently conducted several other fine feature discrimination tasks, such as luminance discrimination and length discrimination of bar segment (Tanaka and Shimojo 1995). These tasks all lead to FOR, thus supporting the idea that the key feature for the FOR-type tasks is the necessity of fine details of object.

23.5 GENERALITY OF IOR ACROSS VARIOUS MOTOR RESPONSES

There was still a question about the nature of the response. So far we had only used button pushing as a response. Could the IOR be generalized to other types of motor response? To investigate the robustness and generality of IOR, we employed a more typical visually guided orienting, saccade eye movement task.

Experiment 1.3: Saccadic Eye Movement Task

Subjects Four subjects participated in the experiment: two naive and two nonnaive (authors).

Stimuli and Apparatus The stimulus set was identical with experiment 1.1, thus target's location, color, and orientation were again randomized across trials. The *Ober2* system (Permobil Inc.) was used for the eye movement recording. The temporal resolution of the measurement was set at 120 Hz, and the spatial resolution on the given condition was at, or better than, 0.3 degree. The subject's head was stabilized by a chin rest and a biting board. The observation distance was set at 40 cm; thus the distance between the fixation point and the target was 17.1 degrees.

Procedure Subjects had to fixate on the fixation point initially and then to move their eyes as quickly as possible to the target when it was presented. Saccade reaction time (SRT) was measured as the delay between the target appearance and the initiation of the eye movement. Two hundred trials were

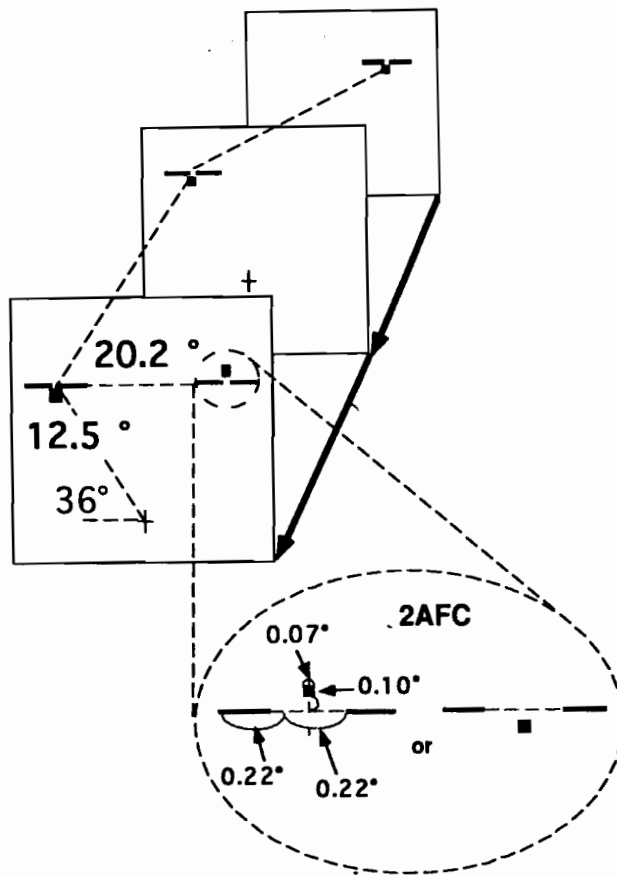


Figure 23.3 A. Vernier discrimination task, in which subject had to make 2AFC judgment as to whether target dot was above or below reference lines (experiment 1.2). B (next page). RT as function of RSI in vernier discrimination experiment. Bold line indicates RT at same location, and thin line indicates RT at different location. Vertical bars show standard error.

obtained from each subject. There were also 50 catch trials, where only the fixation point was presented and subjects were *not* supposed to move their eyes. This procedure was employed just to make sure that the subjects' saccades were really a response to the appearance of the visual target. SRTs below 50 ms and above 1,000 ms were eliminated from the analysis. The data were analyzed primarily in terms of the positional relationship of the targets between the previous and the present trials.

Results and Discussion The results show a strong IOR (see fig. 23.4). A four-way repeated measures ANOVA (RSI \times location \times color \times shape) revealed the main effects of RSI and location as significant ($p < .01$). The results suggest that IOR reflects a common process among spatial orienting tasks (Posner 1980); they are also consistent with a more specific hypothesis that the necessary and sufficient condition for IOR to occur is that a saccade be programmed, but not necessarily executed (Rafal et al. 1989). The RTs were somewhat slower than in the previous studies, presumably because of

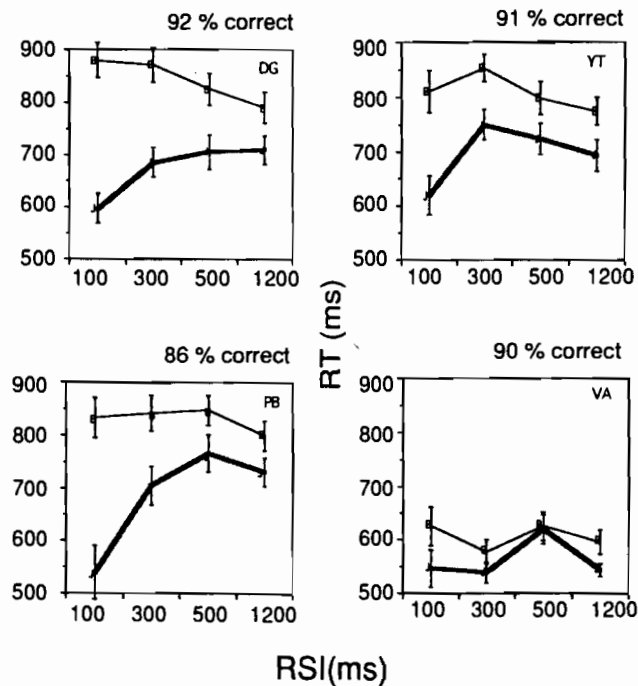


Figure 23.3 (cont.)

the randomization of location, the relatively low luminance, the large distance between the fixation and the target, and the existence of intermingled catch trials (20 percent of the total number of trials).

We also tried an arm-reaching task, in which the subject had to control the cursor on the CRT display by moving a mouse so that the cursor would reach the target as fast as possible. Here, we obtained the same, but somewhat exaggerated, IOR (Tanaka and Shimojo 1995).

23.6 FURTHER TESTS WITH THE POPOUT DISPLAY

To summarize thus far, all of our results indicate a clear dissociation between two types of visual task. One is the spatial orienting task that requires information about presence and global location of the target; this is where the IOR is commonly observed. The other is the feature-analyzing task that requires information about fine features of objects; this is where the FOR is commonly observed.

We would like to jump ahead and ask, Is there a limitation in terms of stimulus complexity for the IOR? It has been commonly believed that the sensory-guided spatial orienting heavily involves some subcortical loci such as the superior colliculus in its underlying neural circuit (Weiskrantz et al. 1974; Robinson 1981; Hikosaka and Wurtz 1983; Schiller, Sandell, and

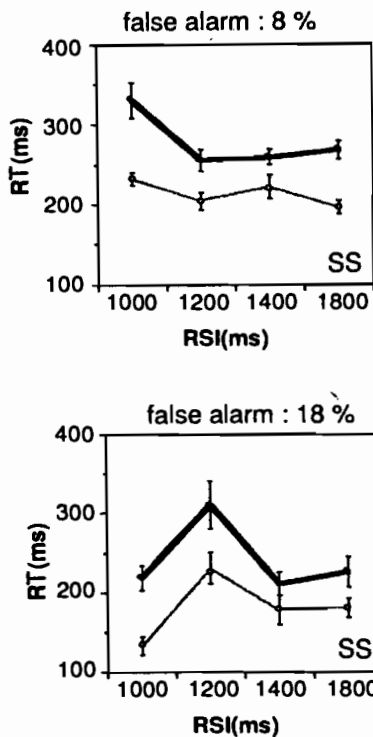


Figure 23.4 RT as function of RSI in saccade eye movement experiment (experiment 1.3). Bold line indicates RT at same location, and thin line indicates RT at different location. Vertical bars show standard error.

Maunsell 1984). Moreover, there seems to be a temporal hemifield dominance for IOR (Rafal et al. 1989). Together with some neuropsychological findings (Rafal et al. 1990), it has been taken as evidence for involvement of the retinotectal pathway in the underlying mechanism. Following this tradition, it might seem reasonable to assume that the neural mechanism underlying the IOR is mostly subcortical. Yet this assumption is far from convincing; most of the currently available studies only considered the simplest situation, where the target was the only visible besides the fixation point.

This raises the question of whether the IOR mechanism could extract global location of the target when there are many visible distractors (Treisman and Gelade 1980). To illustrate, see figure 23.5. In this popout display, the target is defined by a color different from that of distractors around it. According to the latest theory (Duncan and Humphreys 1989), the difficulty of search increases with two factors: increased similarity of targets to nontargets and decreased similarity between nontargets. This is an intriguing case because the location of the "odd-ball" target cannot be obtained unless vigorous, parallel feature analyses and interactions among the analyzers are done. This is presumably impossible to deal with in the subcortical loci such as the superior colliculus (Schiller, Sandall, and Maunsell 1984). Rather, it requires feature analysis, allegedly a part of early cortical processing (Karni and Sagi 1991, 1993; Lamme 1994; Zipser et al. 1994). In other words, the

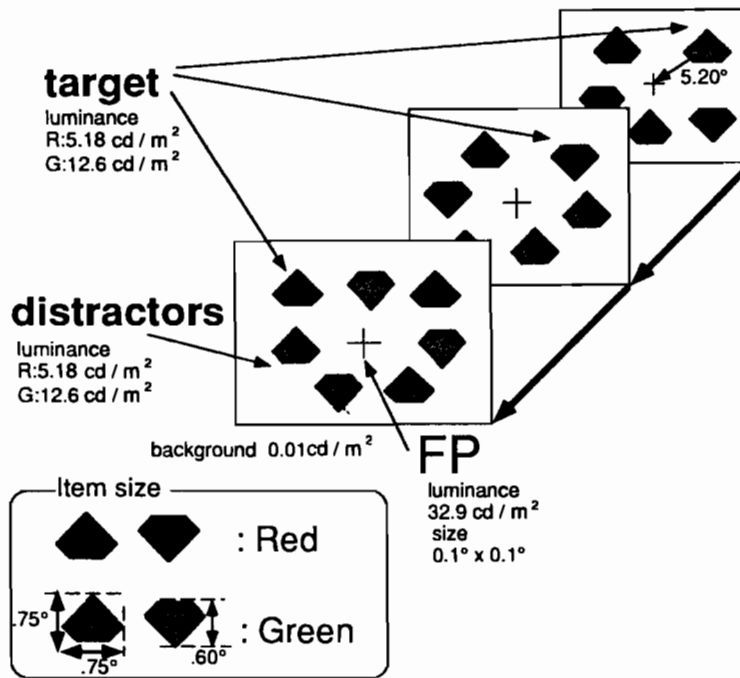


Figure 23.5 Stimulus configuration and sequence for popout experiments (Experiment 1.4).

information abstracted and used for the task is still *global-spatial*, yet it could be obtained only through massively parallel *feature* analysis. Thus, in theory, either the IOR or the FOR would be possible as a prediction, and the results would have an implication about the neural loci of IOR and FOR.

Employing this type of color popout display, we simply duplicated the four tasks (detection; location, color, and shape discrimination) in experiment 1.4.

Experiment 1.4: Popout Displays

Subjects Four subjects participated in the experiment: two naive and two nonnaive (authors).

Stimuli and Apparatus The target was defined by a color different from that of distractors around it, as in the typical experiment of single-feature visual search. The location, color, and shape of the popout target were again randomized. As shown in figure 23.5, the target and each of the distractors were diamond-shaped and were chopped off either at the top or the bottom (stimuli similar to that employed by Maljkovic and Nakayama 1994). The location of the target was randomized between left and right across trials. The locations of the distractors were randomized, and the color of the target were also randomized between red and green across trials. The RSI was randomized among 100, 300, 500 and 1,200 ms. The number of distractors were fixed at fifteen. The viewing distance was 114 cm. The experiment was conducted in a completely dark room.

Procedures Subjects were asked to fixate on the fixation point through the experimental sessions, while performing either a simple detection or a two-alternative, forced-choice discrimination task on the target and responding by mouse buttons. As in experiment 1.1 (single target), the following four tasks were employed in separate sessions: (1) simple detection; (2) location discrimination; (3) color discrimination; and (4) shape discrimination. In the case of color discrimination, subjects had to judge the color of target, and to press one of the mouse buttons accordingly. In the case of shape discrimination, subjects had to judge whether the top or the bottom corner of the diamond-shaped target was chopped off, and to press one of the buttons. This shape discrimination task was similar to that employed by Maljkovic and Nakayama (1994). Note that the target was defined always by color difference from the distractors, even in the shape discrimination.

Subjects initially performed a practice session up to 200 trials to get used to the task, and then an experimental session for each task. The experimental session consisted of 380 trials, including 20 percent of catch trials, where red and green distractors were spatially mixed and no target popped out. The purpose of this procedure was again to make sure that subjects were really responding to the popout stimuli. The data were analyzed primarily in terms of the positional relationship of the targets between the previous and the present trials.

Results and Discussion The results are shown in figure 23.6. Once again, we found IOR in the simple detection and the location discrimination tasks, and FOR in the color and shape discrimination tasks, in all of the four subjects. Moreover, there was a surprising tendency toward exaggerated difference both in IOR and FOR, even taking it into account that the RTs were generally longer with the popout displays than with the single-target displays. A four-way repeated-measures ANOVA (RSI \times location \times color \times shape) was applied to each of the four tasks. The results can be summarized as follows: (1) for the detection and the location discrimination tasks, only the main effect of location reached the significant level ($p < .05$ and $p < .01$, respectively); and (2) for the color discrimination task, the main effects of location ($p < .01$), shape ($p < .05$), and RSI ($p < .01$) were all significant, as were all the interactions of location \times shape ($p < .05$), location \times RSI ($p < .01$), color \times shape ($p < .05$), color \times RSI ($p < .05$), shape \times RSI ($p < .05$), location \times shape \times RSI ($p < .05$), and color \times shape \times RSI ($p < .05$).

We also tried another type of popout display, where the target was defined by orientations of the bar stimuli to obtain basically the same results (Tanaka and Shimojo 1994, 1995). These results further confirmed our initial hypothesis about the distinction between two visual functions. They also indicate the availability of output from the global texture analysis for the IOR mechanism, suggesting significant involvement of cortical areas such as V1 and V2 (Sagi and Julesz 1985; see Tanaka and Shimojo 1995 for more details of Experiment 1).

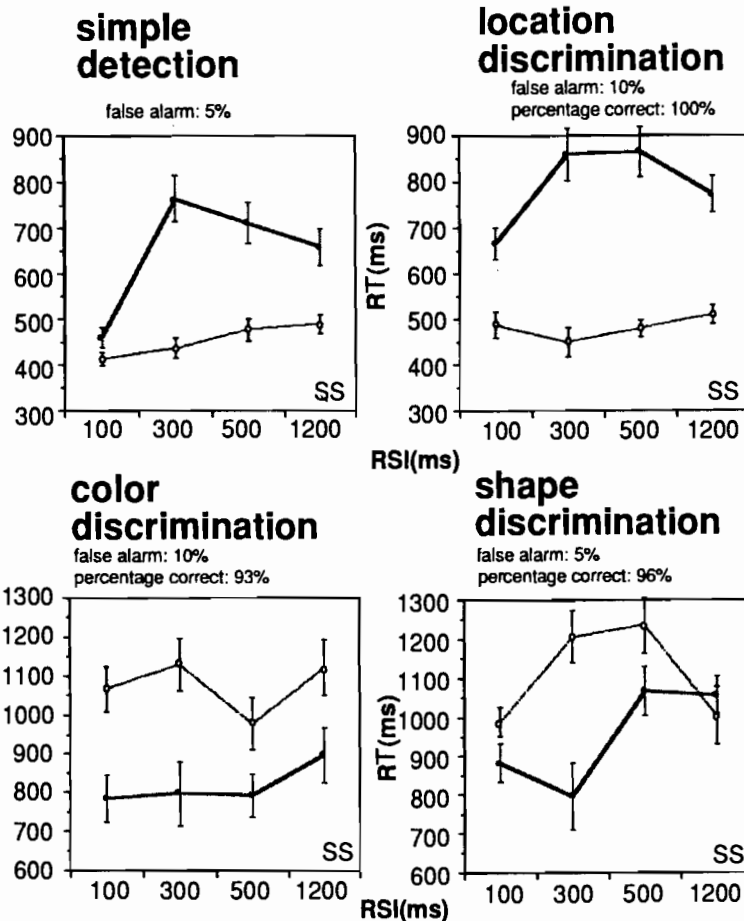
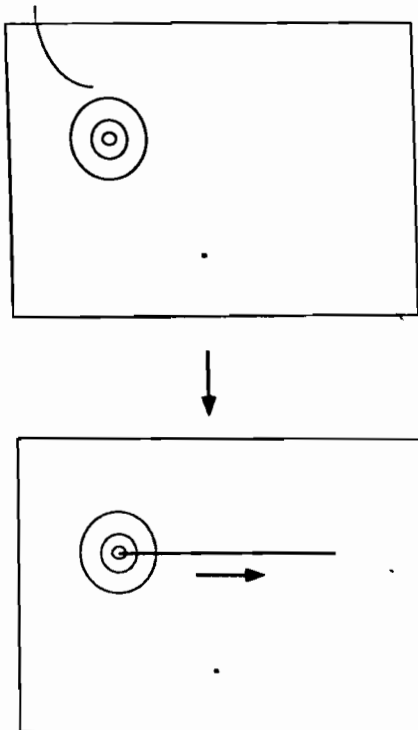


Figure 23.6 RT as function of RSI in color-based popout experiment (experiment 1.4). Results in four different tasks are shown separately in separate panels. Bold line indicates RT at same location, and thin line indicates RT at different location. Vertical bars show standard errors.

23.7 RELATION TO THE DISSOCIATION BETWEEN TWO VISUAL PATHWAYS: A SPECULATION

Our results are at least partly consistent with the well-known neurophysiological distinction between two visual pathways, the ventral-parietal and the dorsal-temporal pathways. They have been characterized as "where" versus "what" (Schneider 1969; Ungeleider and Mishikin 1982; Sagi and Julesz 1985; Duncan 1993; Livingstone and Hubel 1988), or as "action" versus "recognition" (Goodale and Milner 1992).³ We demonstrated a clear dissociation between the two visual functions in RTs. Moreover, we eliminated the nature of the task (detection/discrimination) and of motor responses (button pressing, saccade eye movement, and arm reaching) as a decisive factor for IOR. Thus we identified the type of information the task demands (global location rather than fine characteristics of objects) as a more specific factor for IOR.

Focal Attention



Illusory line motion from
the attended side.

Figure 23.7 Line motion effect. Line probe, presented physically at once, could be seen to unfold from attended side.

Finally, does the dissociation we discovered have any value from the biological or ecological viewpoint? We think it does. Accept the assumption, for the time being, that there are indeed two functional pathways. The "where" or "orienting" pathway is allegedly for orienting to a new stimulus or event in the visual field. Its main purpose is to get ready for an unexpected and unpredictable event elsewhere than the currently attended object, and to respond to it as quickly as possible. This feature would be also very useful to facilitate visual search of any kind because avoiding repeated examinations of the same location would be desirable for finding a target. Thus it would make a lot of sense if this pathway increased sensitivity at new locations while sacrificing sensitivity at the same location.

On the other hand, the "what" or "feature" pathway is allegedly for identifying finer details of the concerned object. Its main purpose is to do feature analysis as much and as deeply as possible for the currently attended object. Thus it would make a biological sense if it increased efficiency at the same location while sacrificing it at different locations. The role of the former (orienting) mechanism is to bring the latter (analysis) mechanism to a new

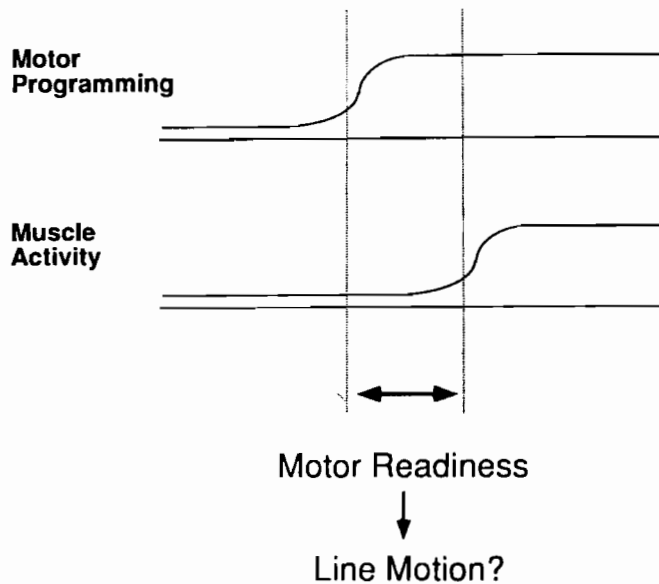


Figure 23.8 Motor readiness, defined as internal process during period from onset of motor programming to onset of actual muscle activity.

location rather quickly. The former may correspond to the mechanism for the transient attention shift, that is, the disengagement/engagement of attention (Posner et al. 1984; Fischer and Breitmeyer 1987), while the latter presumably has a sustained characteristic (Hikosaka, Miyauchi, and Shimojo 1993a). This expectation is consistent with our data in that RTs were in general faster when IOR was observed, while RTs were in general slower when FOR was observed (see figs. 23.2–23.4 and 23.6; also see Tanaka and Shimojo 1995).

23.8 FROM SENSORY TO MOTOR LEVELS: MOTOR PERFORMANCE LEADS TO A LINE MOTION

As noted above, the reaction time task involves many different levels of information processing, from the sensory encoding to the motor programming. Thus it is unclear at what stage the IOR and the FOR occur.

In this regard, it would be intriguing to compare the reaction time paradigm with the line motion paradigm, which we describe elsewhere (see Hikosaka et al., chap. 10, this volume; also see Hikosaka, Miyauchi, and Shimojo, 1993b, c; Shimojo, Miyauchi, and Hikosaka 1992). The line motion is basically an illusory motion illusion, presumably induced by attentional gradient across the visual field (fig. 23.7). It can be induced by a visual cue, a nonvisual (auditory/somatosensory) cue, or voluntary effort; it is object-bound, rather than retinotopic. Because the line motion is a purely visual illusion that does not require any particular kind of motor response, it is reasonable to assume that the neural mechanism underlying this illusion is at a sensory/perceptual level. Thus it would be revealing to compare effects of

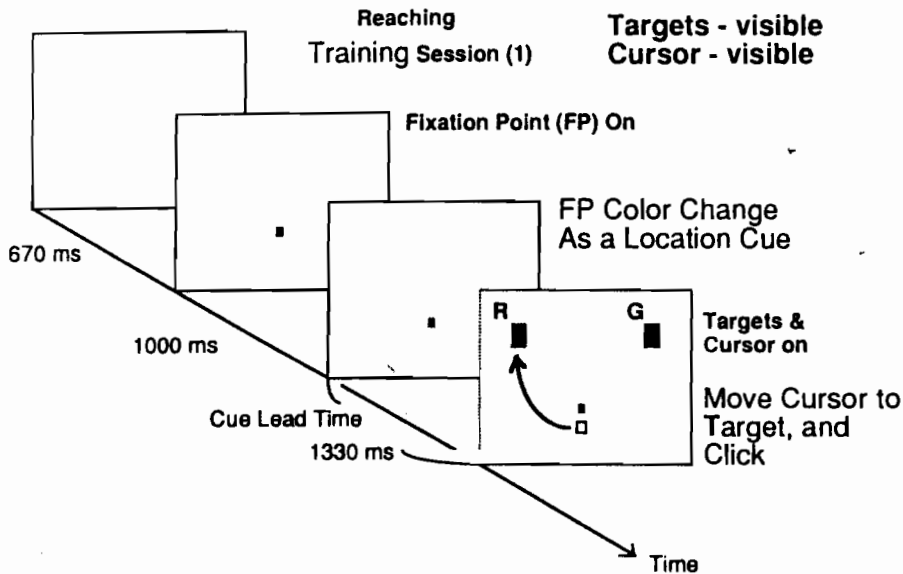


Figure 23.9 A. Stimulus configuration and sequence for arm-reaching training. Two targets were presented, red at left top, and green at right top. Subject's task was to move cursor to target indicated by color change of fixation point, and to click mouse button as quickly as possible. B (next page). Stimulus parameters for arm-reaching task. Stimulus configuration for saccade task, described later in the test, is also shown at bottom.

stimulus parameters on the line motion and various motor tasks, including the reaction time tasks, particularly because IOR indicates a facilitation at the opposite location to the previous stimulus, whereas the line motion indicates a facilitation at the same location.

Shimojo, Miyauchi, and Hikosaka (1993) conducted a series of experiments in which they examined whether motor readiness alone could lead to line motion. (Here we tentatively define *motor readiness* as the internal process for motor response during the period from the onset of motor programming to the onset of actual muscle activity; see fig. 23.8). We report these experiments in some detail below.

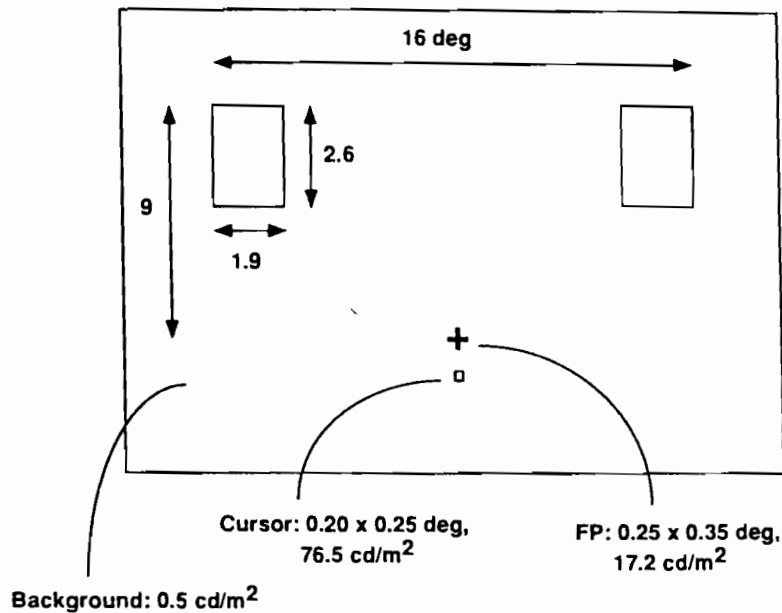
Experiment 2.1: Line Motion from the Goal Location of Prepared Arm Reaching

Because there were quite a few training sessions and test sessions, we first describe the subjects, stimuli, and apparatus, which were the same for all sessions, and then describe the procedures and results of these sessions separately.

Subjects Four subjects participated in all training and test sessions: one naive and three nonnaive (authors).

Stimuli and Apparatus Figure 23.9A illustrates the typical stimulus sequence for the initial training. Initially, the fixation point was presented for

Stimulus Parameters



TASKS		RED	GREEN
Reaching		8.3	10 cd/m^2
Saccade		8.3	10

Figure 23.9 (cont.)

1,000 ms; then it changed its color, either to red or to green, as a location cue. After a cue lead time (1,330 ms), two targets were presented in the periphery. The top panel in figure 23.9B shows the spatial relationship among the fixation point, the targets, the cursor, and their luminances. The stimuli were presented on a CRT display, controlled by a personal computer (Commodore Amiga 3000). The observation distance was 57 cm.

Procedure Subjects participated in two different training sessions before undertaking the test session.

Training session 1: Targets and cursor visible The first training session employed a simple reaching task. Subjects had to move a mouse on a flat surface while monitoring its position on the CRT display so that it reached

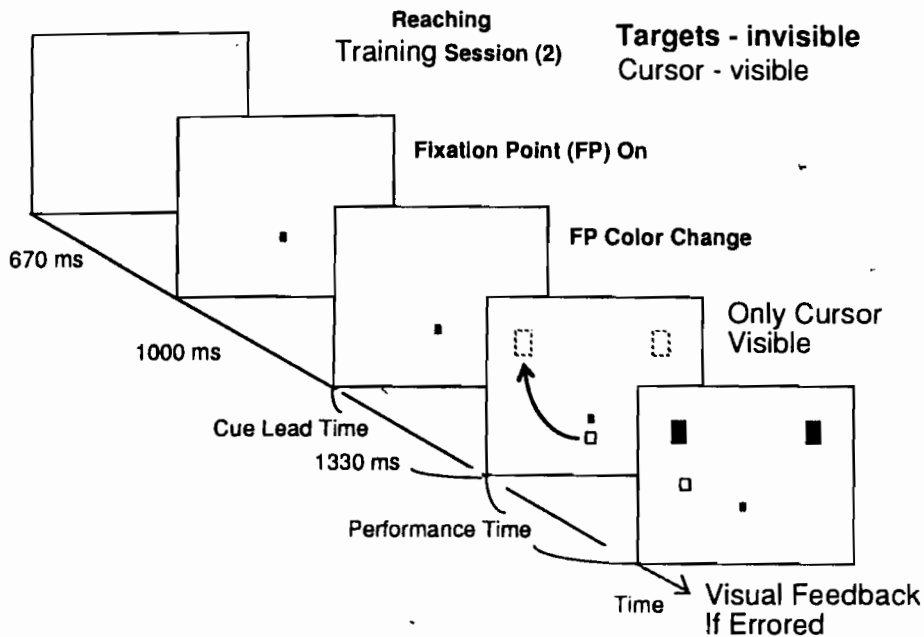


Figure 23.10 Stimulus configuration and sequence for memory-guided arm-reaching task 1. In training session 2, targets were made invisible, while cursor was visible.

the target location as fast as possible; they then had to click the mouse button. In the initial training, the fixation point, the cursor, and the target were all visible (see fig. 23.9A–B for the stimulus sequence and configuration). The red target was always presented at the top left, whereas the green target was at the top right corners of the CRT display. Initially, the subject had to stare at the gray fixation point. The fixation point then changed its color, to either red or green, as a signal for the target location (the colors were randomized across trials). Thus subjects had to move to cursor to the left target if the fixation point turned into red, and to the right target if the fixation point turned into green. Subjects had to fixate on the fixation point all through the trial. This was a relatively easy task, and all the subjects improved rather quickly within 200 trials.

Training session 2: Targets invisible, cursor visible In the second session of training, the targets (and then the cursor) were made invisible, so that subjects had to perform the reaching task based on their memory about the target's location (see fig. 23.10). Subjects initially stared at the fixation point and waited for its color change; they then decoded the meaning of it (red as to the left, green as to the right), moved the cursor to the invisible target, and clicked the mouse button. If subjects clicked the button outside of the target area, then the colored targets were visually presented as a feedback. The target area was made a little larger (about 150 percent of the original size) so that the task was still easy and all the subjects could become accurate within 200 trials.

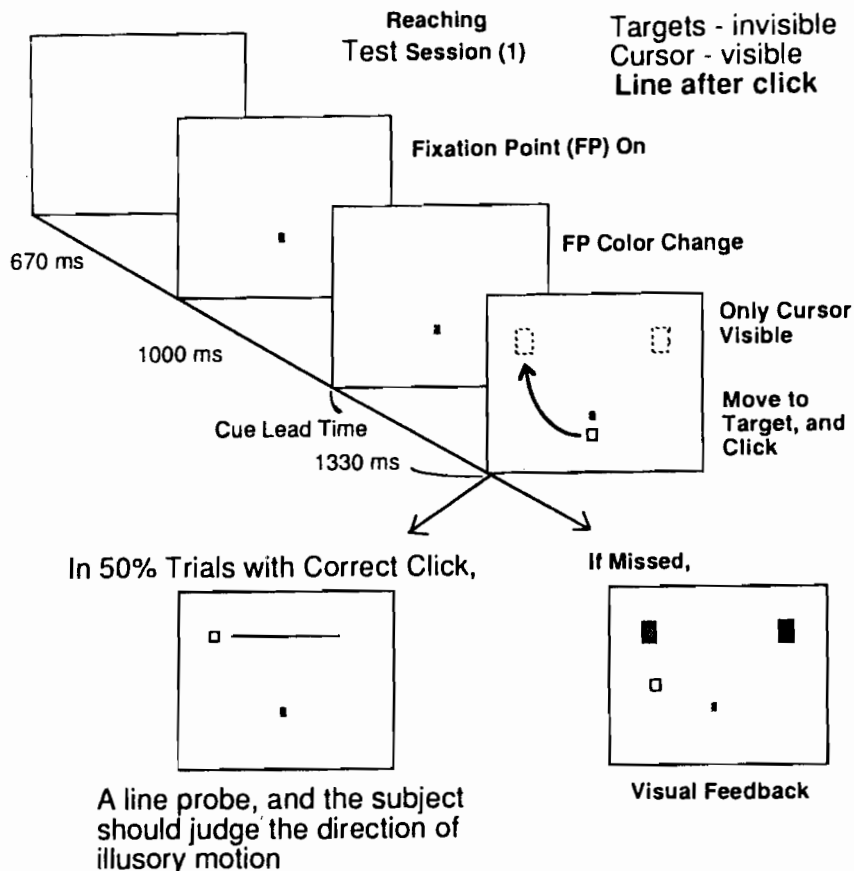


Figure 23.11 Stimulus configuration and sequence for the memory-guided arm-reaching task in test session with line motion (test session 1). Cursor was still visible, and line probe was presented only after the subject's button click response in this case. Line probe was presented in 50 percent of trials, which were randomly mixed with reaching trials.

Test session 1: Targets invisible, cursor visible, and line probe after button click After sufficient amount of training, a line probe was presented in 50 percent of trials, which were randomized and unpredictable (see fig. 23.11). Subjects were asked to judge direction of the perceptual unfolding of line, and it was scored in terms of its relation to the goal position of reaching.

Results and Discussion The line probe was almost always appeared to unfold from the target side, even though it was presented physically at once, as indicated by dark bars in figure 23.12. This was not at all surprising to us because of the visibility of the cursor. That is, the cursor was always visible in the target area when the line was presented, and the line motion could well be induced solely by the visual presence of the cursor. We knew already that a visible cue lead to line motion from the cued side (see Hikosaka et al., chap. 10, this volume).

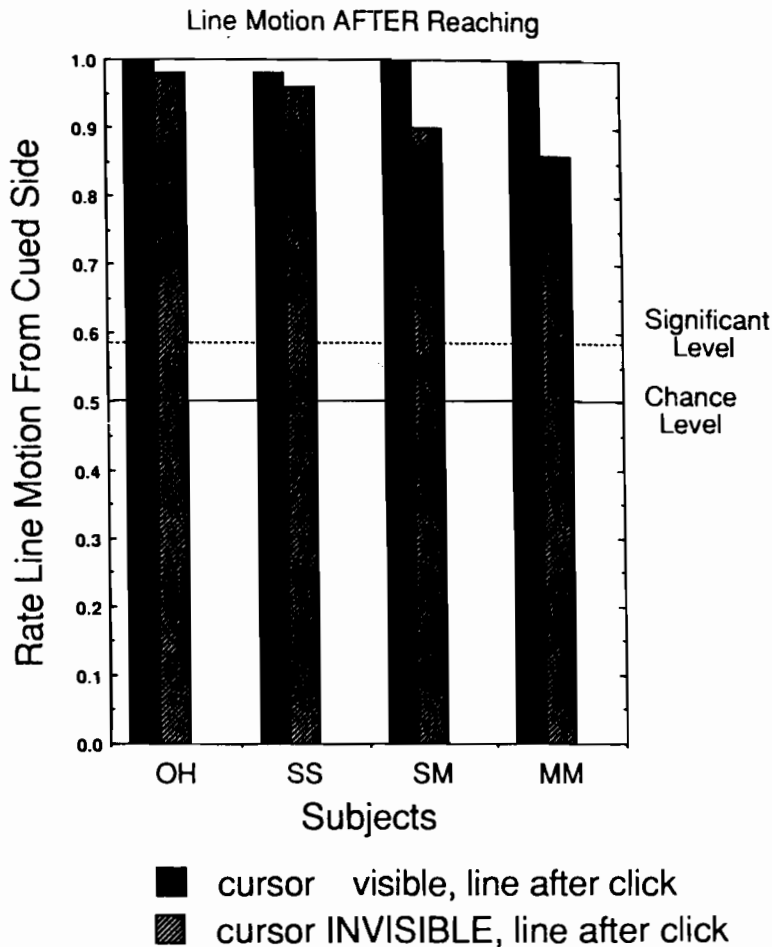


Figure 23.12 Results of the arm-reaching experiments (test session 1 and 2). Rate of line motion from target side is plotted in cursor-visible (filled) and cursor-invisible (shaded) conditions for each subject. In both conditions, line was always presented when subject moved cursor to target's location and clicked mouse button.

23.9 MOTOR PERFORMANCE WITHOUT VISUAL CUE LEADS TO LINE MOTION

To see if the visible cue is the only cause of the line motion, we further conducted the following training and test sessions.

Procedure

Training session 3: Targets invisible, cursor invisible The cursor as well as the targets were now made invisible so that subjects had to rely completely on their memory (see fig. 23.13). Initially, subjects stared at the gray fixation point, whose color changed either to red or to green after 1,000 ms, as in the previous two training sessions. But this time, subjects had to wait until the fixation point blinked as a GO sign. The cue lead time (from the

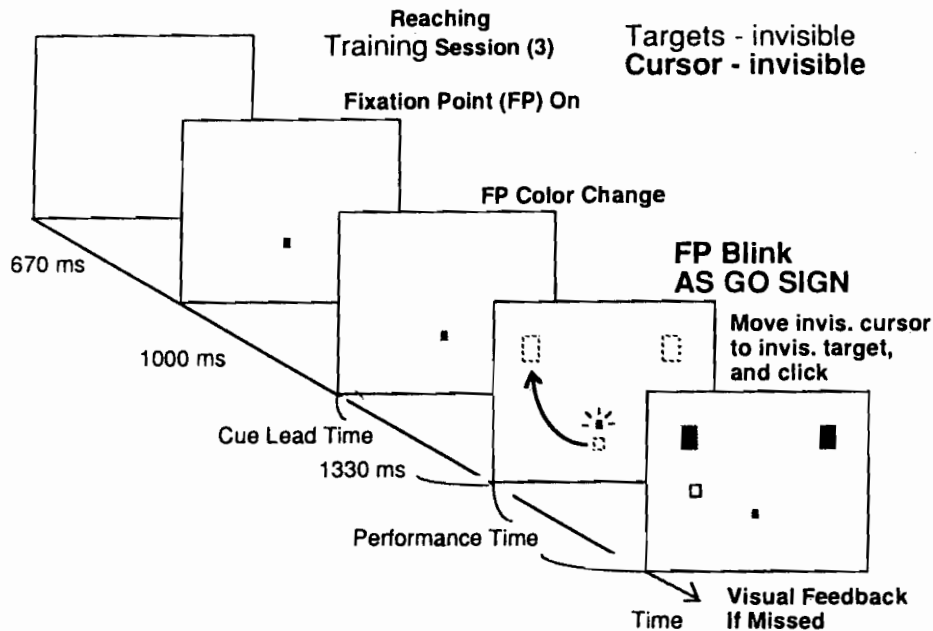


Figure 23.13 Stimulus configuration for memory-guided arm-reaching task 2. Targets and the cursor were both invisible, and subject had to wait for blink of fixation point before moving invisible cursor to invisible target and clicking the mouse button.

color change of fixation point to its blink) was fixed at 1,330 ms in this training session and the following test session. Once the FP blinked, then the subject had to move the invisible cursor quickly to the invisible target, whose location had been indicated by the color change of fixation point. Thus, during the period between the color change of fixation point and its blink, subjects were allowed to get ready but not allowed to actually start the reaching response. Subjects were explicitly instructed to "move the cursor as quickly and as accurately as possible, when the fixation point blinks" so that they were forced to develop specific motor readiness during the waiting period.

This task was more challenging, as would be easily suspected, but turned out not to be impossible, particularly when the target zone was made much larger and sufficient number of trials were given. In fact, the "correct" target zone was enlarged ($\times 2$, both horizontally and vertically) to make this memory-guided task feasible. Training sessions were repeated until the success rate reached about 95 percent of trials. As a result, the subjects performed from 100 to 400 trials. When subjects reached the criterion, the second test session was given.

Test session 2: Targets invisible, cursor invisible, and line probe after button click A line probe was presented in 50 percent of trials, which were randomized and unpredictable. The line probe presented when subjects thought they reached the invisible target with the invisible cursor and thus

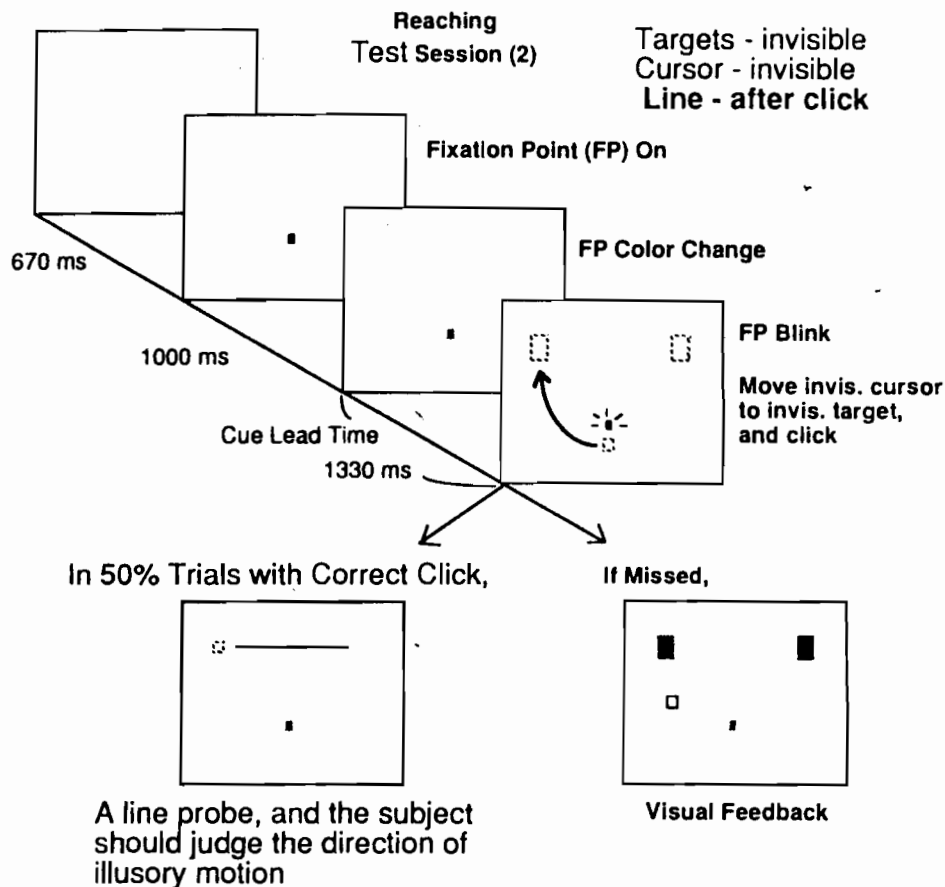


Figure 23.14 Stimulus configuration and sequence for memory-guided arm-reaching task 2 in test session with line motion (test session 2). Targets and cursor were both invisible, and line probe was presented at (and thus only after) subject's button click response. Line was presented in 50 percent of trials, which were randomly mixed with arm-reaching trials. Results are shown as shaded bars in figure 23.12.

clicked the mouse button (see fig. 23.14). Subjects had to judge from which side the line appeared to be drawn.

Results and Discussion The "probe line consistently appeared to unfold from the target side for all of the four subjects, as indicated by shaded bars in figure 23.12. This was a new finding because nothing occurs anywhere in the visual field, except for the fixation point, which stayed in the middle, when the line probe was presented. Thus the line motion effect should be attributed to the motor response.

However, there was still an ambiguity in interpreting these results. There was a possibility that the line motion could be induced by nonvisual sensory feedback, that is, by somatosensory and kinesthetic feedback from the reaching movement. This was possible because Shimojo, Miyauchi, and Hikosaka (1992) had already shown that nonvisual cues, such as a somatosensory or auditory cues, could also lead to line motion.

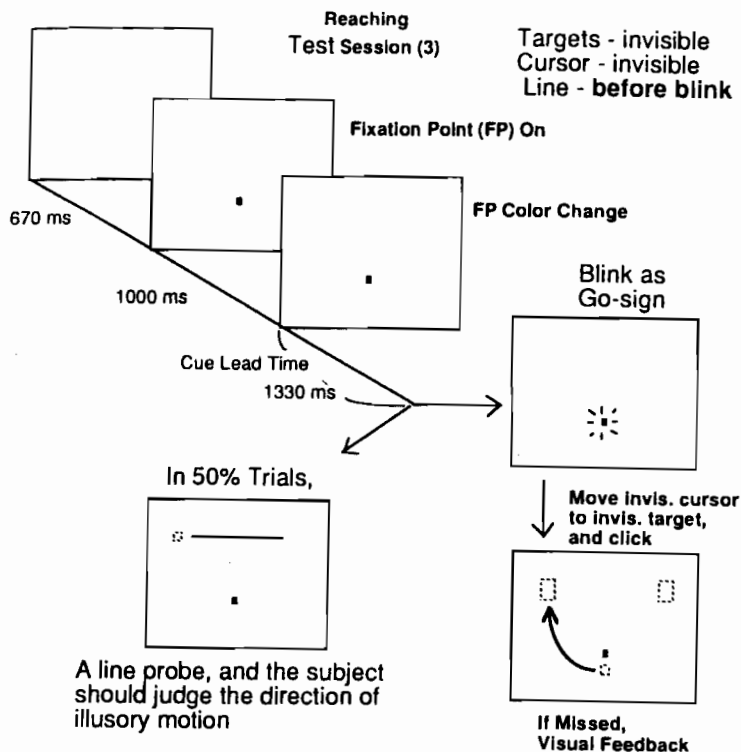


Figure 23.15 Stimulus configuration and sequence for memory-guided arm-reaching task 2 in test session with line motion (test session 3). Targets and cursor were both invisible, and this time, line probe was presented *after* color change but *before* blink of fixation point (GO sign). Line was presented in 50 percent of trials, which were randomly mixed with arm-reaching trials.

23.10 SENSORY FEEDBACK, OR MOTOR READINESS?

Procedure

Test session 3: Targets invisible, cursor invisible, and line probe before arm movement button click So in the third test session, we presented a line probe *after* the color change but *before* the disappearance of the fixation point. This was done in 50 percent of the trials, which were randomly mixed with the ordinary invisible reaching trials (see fig. 23.15). Note that during the period between the color change and the blink of the fixation point, motor preprogramming or internal readiness would develop, but there was no muscle response and no kinesthetic or somatosensory feedback either. We reasoned that if the line motion was still observed, then it should be attributed to motor readiness *per se*, which was isolated from sensory feedback such as visual, kinesthetic or somatosensory.

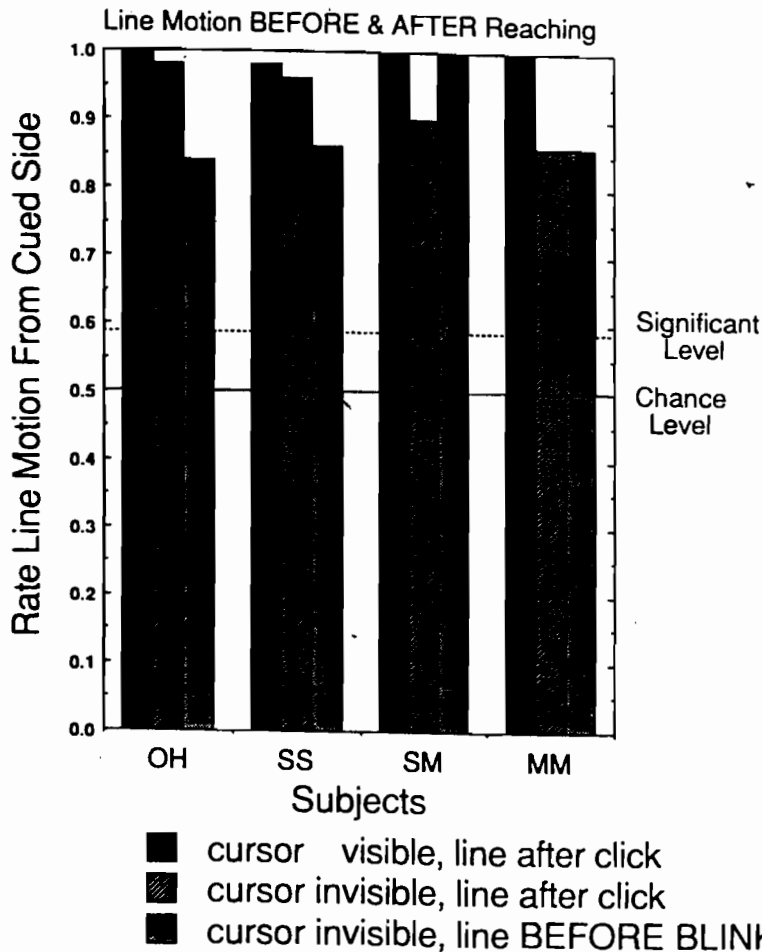


Figure 23.16 Results of "line before GO sign" condition (test session 3). Rate of line motion from target side is plotted for "line before GO sign" condition (gray, rightmost bar for each subject). Results for previous two conditions (cursor visible, line after click—black, leftmost bars; and cursor invisible, line after click—shaded, middle bars) are shown again for comparison.

Results and Discussion The results were indicated by light gray bars in figure 23.16. Even though the rate of line motion from the cued (motor readiness) side was slightly less than the other two conditions in all of the subjects, it was still well beyond the statistically significant level of $p = 0.5$.

Thus we found that internal readiness for the orienting response was sufficient to yield the line motion effect. This suggests that motor preprogramming facilitates visual information processing locally near the goal location, which in turn yields the illusion of line motion (the "prior entry" hypothesis; Hikosaka, Miyauchi, and Shimojo 1993a, b, c). It seems likely that the kind of attention that is triggered by memory-guided motor programming is related at least partly to the kind of attention that has been tapped by the line motion paradigm.

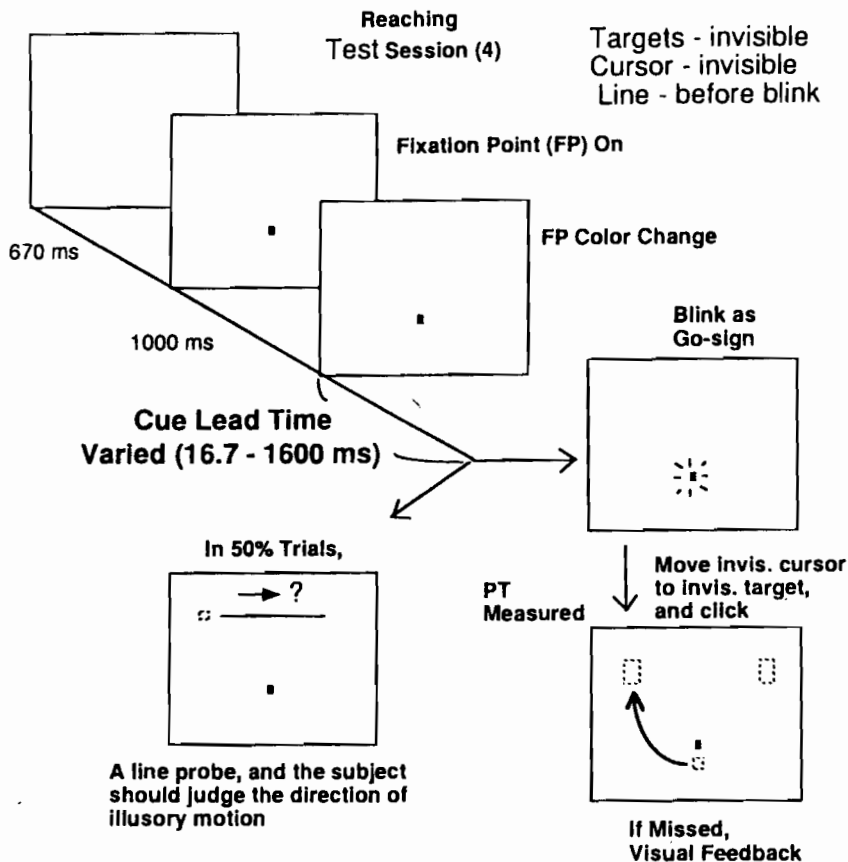


Figure 23.17 Stimulus configuration and sequence for the memory-guided arm-reaching task 2 in test session with line motion (test session 4). Conditions were same as those illustrated in figure 23.15, except that cue lead time was randomized (16.7–1,600 ms) across trials to assess rising time course of line motion effect.

By randomly manipulating the cue lead time (from the color change of fixation point to its blink as GO sign) among the trials, we could even assess the rising time course of motor readiness. This was what we tried in the last test session.

Procedure

Test session 4: Targets invisible, cursor invisible, and line probe before arm movement with cue lead time varied The stimuli and the procedure were the same as those in test session 3, except that the cue lead time was randomized in eight steps (16.7–1,600 ms) across trials (see fig. 23.17), and the results were analyzed in relation to the cue lead time.

Results and Discussion For an example of results, see figure 23.18, where we plotted the rate of line motion from the cued (motor readiness) side as a function of cue lead time (the solid curve in the figure). Also plotted is the

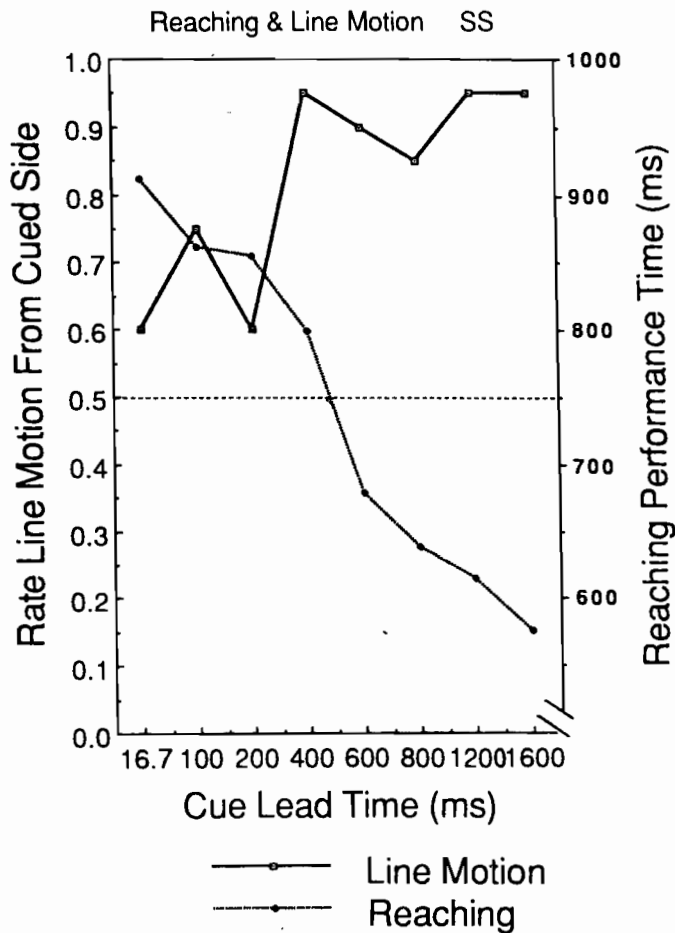


Figure 23.18 Results of the arm-reaching line motion experiment, with the cue lead time randomized (test session 4). Rate of line motion from cued (target) side is plotted against cue lead time for one subject as example (solid curve). Mean performance time of arm-reaching at each cue lead time was also calculated from arm-reaching trials and plotted in same panel (dotted curve).

performance time of reaching, which has been calculated from the reaching trials in the same test session (the dotted curve in the figure). As obvious in the figure, the rising time course of line motion was inversely correlated with the performance time of reaching, as the waiting time increased. The results were similar in this regard, though somewhat noisier, for the other subjects. This suggests that the attentional mechanism reflected in the line motion might in fact be related to the motor readiness for reaching.

23.11 SACCADE READINESS WITH THE LINE MOTION

To see if the finding could be generalized to another kind of motor response, we employed a saccadic eye movement task.

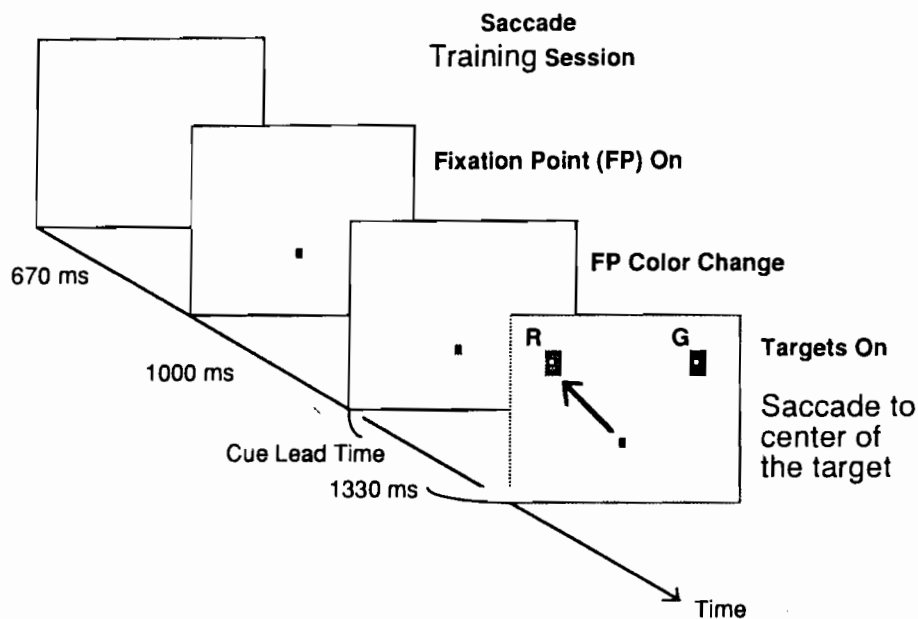


Figure 23.19 Stimulus configuration and sequence for saccade training (experiment 2.2). Stimulus parameters were very similar to those in arm-reaching experiments. Subject's task was to move eyes as quickly as possible to relevant target, which was indicated by color change of fixation.

Experiment 2.2: Line Motion from the Goal Location of Saccadic Eye Movement

Subjects Three of the authors participated in the experiment as the subjects.

Stimuli, apparatus and procedure All the details of experimental design were virtually identical to those in experiment 2.1 (see fig. 23.9B for the stimulus configuration), except for the nature of the task, which was to make a saccadic eye movement to the target as fast as possible. The saccade recording was done by the *Ober2* system. Subjects first participated in a training session (up to 200 trials; see fig. 23.19), and then a test session in which 50 percent of line probe trials were randomly mixed with the saccade trials (see fig. 23.20). The cue lead time was randomized in the same way as in the arm-reaching/line motion experiment (experiment 2.1, test session 4).

Results and Discussion We obtained essentially the same results. When the line probe was presented during the saccade readiness period (after the color change and before the blink of the fixation point), then the line appeared to unfold from the prepared goal location of the saccade. The rising time course of line motion in the saccade session (the thick curve in fig. 23.21) was quite comparable with that in the arm-reaching session (the thin curve in the figure). This was so for two other subjects as well.

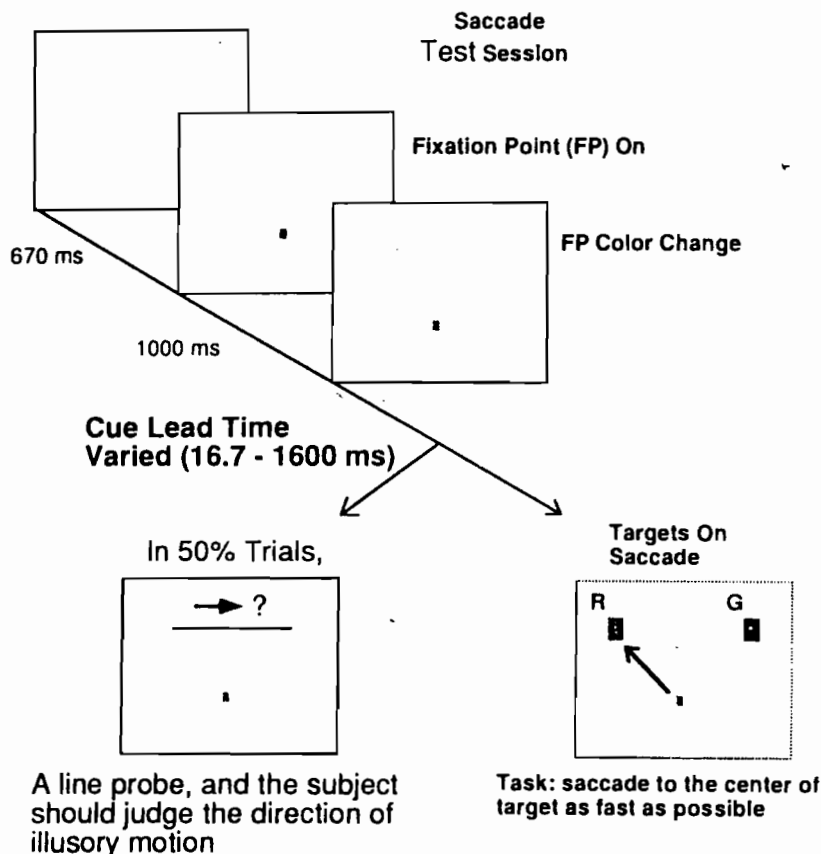


Figure 23.20 Stimulus configuration and sequence for saccade task, with line motion (experiment 2.2). Just as in arm-reaching experiment (2.1; see fig. 23.17), line probe was presented with varying cue lead time *before* blink of fixation point as GO sign. These line probe trials were 50 percent of total trials, and were again randomized with the saccade trials.

Thus the rising time courses of focal attention indicated by the line motion were very similar between two types of motor responses, saccadic eye movement and arm reaching. It is consistent with the idea that readiness or preprogramming for response to a particular target location is alone sufficient to yield a local facilitation strong enough to induce an illusory line motion. Some previous studies also have provided similar data (e.g., Rizzolatti et al. 1987; Klein 1980), though without the line motion as a measure.

23.12 A COMMON ATTENTION MECHANISM?

On the other hand, this does not necessarily mean that the line motion, which is a visual effect, and the motor programming, which is by definition non-visual, could not be dissociable in terms of the relevant attention mechanism. We have several reasons for this skepticism. First, our subjects had been trained *visually* in the first training sessions; that is, their motor performance was guided by *visual* input and feedback. And even in the later training and

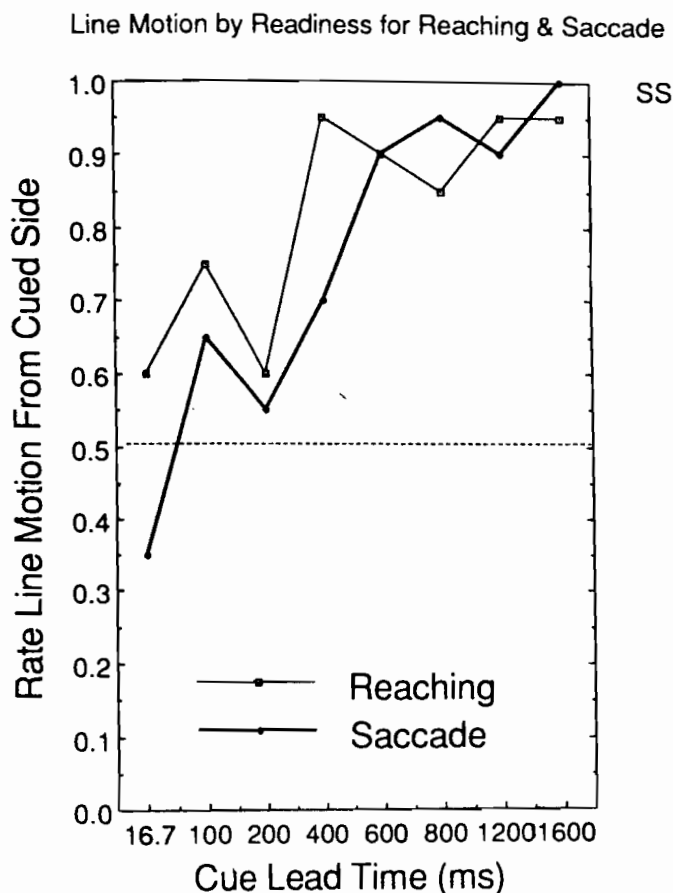


Figure 23.21 Results of saccade line motion experiment, with cue lead time randomized (experiment 2.2). Rate of line motion from the cued (target) side is plotted against cue lead time for one subject as an example (thick curve). Rate of line motion for same subject in previous arm-reaching experiment (2.1; see fig. 23.18) is replotted for comparison (thin curve).

tests, their performance was heavily based on *visual* memory. This could potentially explain why motor readiness inevitably triggered local facilitation at the target location in the *visual* field, which in turn led to a line motion.

Second, we actually conducted another subexperiment, where stimulus configuration and sequence were similar to the previous experiments. The only differences were that top half or the bottom half of the target was randomly chosen and made slightly brighter than the other half, and that subjects had to indicate which of the halves was brighter by a button-pressing response (a two-alternative, forced-choice task). Thus subjects still had to decode the meaning of color change of the fixation point to decide which target would be task-relevant, but also to constantly fixate on the fixation point and simply to do a visual discrimination task as fast as possible when the GO sign (= the blink of the fixation point) was given. Thus in order for the fastest response, subjects had to develop a visual expectation as to which location the relevant target would be at, and mentally "wait right there." We

then randomized 50 percent of line probe trials with the rest of visual discrimination trials by varying the cue lead time, just as we did in the previous experiments. That is, the line probe was presented without the target in 50 percent of trials. As a result, we obtained a rising time course of line motion, which turned out to be highly similar to that obtained in the arm-reaching or the saccade experiments. This result could lead in two directions, however. On one hand, it could suggest the commonality of attentional mechanism between the motor and the visual tasks. That is, a single attentional mechanism could underly the motor programming and the line motion. But by the same token, it could also suggest that the attentional mechanism underlying the line motion during the motor readiness might still be *visual* in nature, owing to the heavily visual feedback/memory in the training.

Third and finally, there have been some studies in the literature that have failed to find evidence for attentional shift to the target prior to a particular motor response such as a saccade (Jon Driver, personal communication; Stelmach, Campsall, and Herdman 1993), while other studies have confirmed this possibility (Posner 1980; Klein 1980); it is still highly controversial (Remington and Pierce 1984).

For these reasons, it seems premature to conclude that a single attentional mechanism is underlying the memory-guided motor programming and the line motion. To be conservative, we could only conclude that motor readiness leads to a visual attentional effect at least under some conditions.

23.13 SUMMARY, CONCLUSIONS AND FUTURE DIRECTIONS

We found that *inhibition of return* occurred when the task required global spatial information, regardless of the nature of task, whether it was detection or discrimination. Inhibition of return also occurred in different kinds of motor tasks, such as the saccade eye movement or the arm-reaching tasks.

We found a opposite tendency, namely, *facilitation of return*, when the task required detailed feature of the target, such as color, shape, or vernier offset, even when the stimulus parameters were identical as before. This dichotomy seemed to be consistent with the neurophysiological dichotomy between the "where" and the "what" pathways.

Somewhat surprisingly, we also found the same kind of task-dependent dichotomy when the popout display was employed. This indicates that even when the task-demanded information of global location is based on parallel feature analysis, it still leads to *inhibition*, rather than facilitation. Thus it seems likely that the neural pathway underlying the inhibition of return significantly involves early cortical levels.

In the second half of the chapter, we raise the question of whether motor readiness alone can lead to purely visual attentional effect, that is, the line motion. The answer was yes both for the arm-reaching and the saccade tasks; the observed line motion effect could not be attributed to any kind of visual cue or nonvisual sensory feedback.

This does not necessarily indicate that the same attention mechanism is shared in the two cases, the motor readiness and the line motion. It could simply mean that motor readiness alone is sufficient to yield local facilitation of visual processing, which is responsible for the line motion, particularly when the subjects have been trained to perform the motor task based upon visual memory.

Also, our data have not yet addressed the original issue, namely, at which level the inhibition and facilitation of return occur, whether sensory, sensory-motor, or motor. In this regard, it would be interesting to compare the reaction time paradigm with the line motion paradigm, holding stimulus parameters as close as possible. This seems to be a promising way to resolve the prickly issue in the field: that is, of how many "attention mechanisms" we have to deal with.

ACKNOWLEDGMENT

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NOTES

1. It is believed that IOR occurs only when the peripheral cue is not informative, that is, when it does not predict the location of the target (Posner 1980; Posner and Cohen 1984). However, Tanaka and Shimojo (1993) systematically manipulated the probability that the target was presented at the same location as the previous target, successfully isolating the IOR from the predictability effect. For example, they compared two independent sessions: one in which the target was presented at the same location with $p = .8$ (the opposite location with $p = .2$), and the other in which it was presented at the opposite location with $p = .8$ (the same location with $p = .8$). They found that the RTs at the same locations in the former session tended to be larger than the RTs at the opposite locations in the latter session, even though the predictabilities were the same ($p = .8$). Thus the "location priming" (i.e., IOR) could be isolated from the "probability priming."

2. In fact, recent studies suggest that there might be two types of IOR, one related to eye movements and the other related to stimulus detection (Abrams and Dobkin, 1994; Tipper et al. 1994).

3. Goodale and Milner (1992) considered both the "action" and the "recognition" functions related to the "what" function in Ungeleider and Mishkin's (1982) terminology, so these two distinctions were not identical. To understand our data, we prefer "orienting" versus "feature analyses" as the best characterization.

REFERENCES

Abrams, R. A., and Dobkin, R. S. (1994). Object- and environment-based inhibition of return of visual attention. *Journal of Experimental Psychology: Human Perception and Performance*, 20, 467-477.

- Broadbent, D. E. (1958). *Perception and communication*. Boston: Pergamon Press.
- Duncan, J. (1993). Coordination of what and where in visual attention. *Perception*, 22, 1261–1270.
- Duncan, J., and Humphreys, G. W. (1989) Visual search and stimulus similarity. *Psychological Review*, 96, 433–458.
- Fischer, B., and Breitmeyer, B. (1987). Mechanisms of visual attention revealed by saccadic eye movements. *Neuropsychologia*, 25, 73–83.
- Gibson, B., and Egeth, H. (1994). Inhibition of return to object-based and environment-based locations. *Perception and Psychophysics*, 55, 323–339.
- Goodale, M. A., and Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neuroscience*, 15, 20–25.
- Helmholtz, H. (1909/10). *Handbuch der Physiologischen Optik*. Hamburg: Verlag von Leopold Voss (Reprinted in Southall, J. P. C. (Ed.), New York: Dover, 1962).
- Hikosaka, O., Miyauchi, S., and Shimojo, S. (1993a). Voluntary and stimulus-induced attention detected as motion sensation. *Perception*, 22, 517–526.
- Hikosaka, O., Miyauchi, S., and Shimojo, S. (1993b). Focal visual attention produces illusory temporal order and motion sensation. *Vision Research*, 33, 1219–1240.
- Hikosaka, O., Miyauchi, S., and Shimojo, S. (1993c). Visual attention revealed by an illusion of motion. *Neuroscience Research*, 18, 11–18.
- Hikosaka, O., and Wurtz, R. H. (1983). Effects on eye movements of a GABA agonist and antagonist injected into monkey superior colliculus. *Brain Research*, 272, 368–372.
- James, W. (1890). *The principles of psychology*. New York: Dover.
- Karni, A., and Sagi, D. (1991). Where practice makes perfect in texture discrimination: Evidence for primary visual cortex plasticity. *Proceedings of the National Academy of Sciences*, 88, 4966–4970.
- Karni, A., and Sagi, D. (1993). The time course of learning a visual skill. *Nature*, 365, 250–252.
- Klein, R. (1980). Does oculomotor readiness mediate cognitive control of visual attention? In R. Nickerson (Ed.), *Attention and performance VIII*, 259–276. Hillsdale, NJ: Lawrence Erlbaum.
- Kwak, H. W., and Egeth, H. (1992). Consequences of allocating attention to locations and to other attributes. *Perception and Psychophysics*, 51, 455–464.
- Lamme, V. (1994). Neural correlates of figure-ground segregation in primary visual cortex. *Investigative Ophthalmology and Visual Science*, 35, 1489. Abstract.
- Livingstone, M., and Hubel, D. (1988). Segregation of form, color, movement, and depth: Anatomy, physiology and perception. *Science*, 240, 740–749.
- Maljkovic, V., and Nakayama, K. (1994). Priming of popout. I. Role of features. *Memory and Cognition*, 22, 657–672.
- Maylor, E. (1985). Facilitatory and inhibitory components of orienting in visual space. *Attention and Performance*, 11, 189–194.
- Nissen, J. M. (1985). Accessing features and objects: Is location special? *Attention and Performance*, 11, 205–218.
- Pashler, H., and Baylis, G. (1991) Procedural learning. II. Intertrial repetition effects in speed-choice tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 17, 33–48.

- Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, 32, 3–25.
- Posner, M. I., and Cohen, Y. (1984). Components of visual orienting. *Attention and Performance*, 10, 531–556.
- Posner, M. I., Walker, J. A., Friedrich, F. J., and Rafal, R. D. (1984). Effects of parietal injury on covert orienting of attention. *Journal of Neuroscience*, 4, 1863–1874.
- Rafal, R. D., Calabresi, P. A., Brennan, C. W., and Sciolito, T. K. (1989). Saccade preparation inhibits reorienting to recently attended locations. *Journal of Experimental Psychology: Human Perception and Performance*, 15, 673–685.
- Rafal, R. D., Smith, J., Krantz, J., Cohen, A., and Brennan, C. (1990). Extrageniculate vision in hemianopic humans: Saccade inhibition by signals in the blind field. *Science*, 250, 118–121.
- Remington, R., and Pierce, L. (1984). Moving attention: Evidence for time-invariant shifts of visual selective attention. *Perception and Psychophysics*, 35, 393–399.
- Rizzolatti, G., Riggio, L., Dascolo, I., and Umiltà, C. (1987). Reorienting attention across the horizontal and vertical meridians: Evidence for favor of a premotor theory of attention. *Neuropsychologia*, 25, 31–40.
- Robinson, D. A. (1981). Control of eye movements. In Brooks, V. B. (Ed.), *Handbook of physiology*, vol. 2 pt. 2, 1275–1320, Bethesda, MD: American Physiological Society.
- Sagi, D., and Julesz, B. (1985). “Where” and “what” in vision. *Science*, 228, 1217–1219.
- Schneider, G. E. (1969). Two visual systems. *Science*, 164, 895–902.
- Schiller, P. H., Sandall, J. H., and Maunsell, J. H. R. (1984). The effect of superior colliculus and frontal eye field lesions on saccadic latency in the monkey. *Neuroscience Abstract*, 10, 60.
- Shimojo, S., Miyauchi, S., and Hikosaka, O. (1992). Visual motion sensation yielded by non-visually driven attention. *Investigative Ophthalmology and Visual Science*, 33, 1262. Abstract.
- Shimojo, S., Miyauchi, S., and Hikosaka, O. (1993). Line motion can be induced by visual expectation and memory, guided motor readiness. *Investigative Ophthalmology and Visual Science*, 34, 1290. Abstract.
- Stelmach, L. B., Campsall, J. M., and Herdman, C. M. (1993). Allocation of attention prior to a saccade. *Investigative Ophthalmology and Visual Science*, 34, 1233. Abstract.
- Tanaka, Y., and Shimojo, S. (1993). Location priming and probability priming are isolatable in detection and discrimination. *Investigative Ophthalmology and Visual Science*, 34, 1234. Abstract.
- Tanaka, Y., and Shimojo, S. (1994). Location versus feature: Two visual functions separated by reaction time in the popout display. *Investigative Ophthalmology and Visual Science*, 35, 1619. Abstract.
- Tanaka, Y., and Shimojo, S. (1995). Location vs. feature: reaction time reveals dissociation between two visual functions. *Vision Research*, in press.
- Tassinari, G., Aglioti, S., Chelazzi, L., Marzi, C. A., and Berlucchi, G. (1987). Distribution in the visual field of the costs of voluntarily allocated attention and of the inhibitory aftereffects of covert orienting. *Neuropsychologia*, 25, 55–71.
- Tassinari, G., Aglioti, S., Chelazzi, L., Peru, A., and Berlucchi, G. (1994). Do peripheral non-informative cues induce early facilitation of target detection? *Vision Research*, 34, 179–189.
- Terry, K. M., Valdes, L. A., and Neill, T. (1994). Does “inhibition of return” occur in discrimination tasks? *Perception and Psychophysics*, 55, 279–286.

Tipper, S. P., Weaver, B., Jerreat, L. M., and Burak, A. L. (1994). Object- and environment-based inhibition of return of visual attention. *Journal of Experimental Psychology. Human Perception and Performance*, 20, 478–499.

Treisman, A. M., and Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, 12, 97–136.

Ungeleider, L. G., and Mishkin, M. (1982). Two cortical visual systems. In D. J. G. Ingle and J. W. Mansfield (Eds.), *Analysis of visual behavior*, 549–586. Cambridge, MA: MIT Press.

van der Heijden, A. H. C. (1991). *Selective attention in vision*. London: Routledge.

Weisklanz, L., Warrington, E. E., Sanders, M. D., and Marshall, J. (1974). Visual capacity in the hemianomic field following a restricted occipital ablation. *Brain*, 97, 704–728.

Zipser, K., Lee, T. S., Lamme, V. A. F., and Schiller, P. H. (1994). Invariance of figure-ground mechanisms in V1 for depth, orientation, luminance and chrominance cues. *Invest. Ophthalmol. Vis. Sci.* 35: 4.