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# Repetition Priming Reveals Sustained Facilitation and Transient Inhibition in Reaction Time

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**Repetition priming reveals sustained facilitation  
and transient inhibition in reaction time**

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**Abstract**

Reaction time (RT) in a detection or a location discrimination task increases when a target is repeatedly presented at the same location (inhibition), while RT decreases in the feature (color or orientation) discrimination tasks (facilitation). Here, the time course of inhibition and facilitation was examined, using a repetition priming paradigm. Results indicate that inhibition occurred only in the immediately successive trial, whereas facilitation accumulated over several trials with location repetition. Moreover, inhibition and facilitation occurred in a task-relevant manner: detection/location discrimination produced transient RT increase, whereas feature discrimination tasks produced cumulative RT decrease. These results suggest a functional dissociation between spatial orienting and feature analysis, as well as top-down modulations by tasks leading to different types of visual memory.

## 1 Introduction

Visual attention is often described as a selective process of perceptual performance at a specific visual field (Posner, 1980; Posner et al., 1980; Remington, 1980). Posner and Cohen (1984) found an inhibitory component of spatial attention, which is named “*inhibition of return*” (IOR). Reaction Time (RT) for detecting a visual target is *longer* (inhibition) when cue and target are presented repeatedly at the same location. This holds especially when the interval between cue and target onset (Stimulus Onset Asynchrony; SOA) is relatively long (300-2000 msec) (Posner and Cohen, 1984; Maylor, 1985; Kwak and Egeth, 1992). The inhibition can be explained by an “attention disengagement” process (Posner et al., 1984). Attention is ‘released’ or ‘disengaged’ when it is attracted to a new location, and is shifted to the location immediately. The new location has an advantage for detection (=facilitation), producing relative inhibition (slow response) at the previous location (Posner and Cohen, 1984; Posner et al., 1984).

In our previous studies (Tanaka and Shimojo, 1993; Tanaka and Shimojo, 1994; Tanaka and Shimojo, 1995a; Shimojo and Tanaka, 1995; Tanaka and Shimojo, 1995b; Tanaka and Shimojo, 1996a; Shimojo et al., 1996a), we replicated inhibition (IOR) in a simple detection task (Posner and Cohen, 1984), in a location discrimination task (Maylor, 1985), and in a saccadic eye-movement task (Posner and Cohen, 1984; Rafal et al., 1989), using a target-target paradigm (Mayor and Hokey, 1985; Kwak and Egeth, 1992). In this paradigm, a target was randomly and sequentially presented either at

the same or at the opposite location to the previous target. There was no cue. Subjects responded to each target, and RT was measured each time. RTs were longer when the target was presented at the same location as in the previous trial, exemplifying the phenomenon of IOR.

Surprisingly, inhibition turned into **facilitation**, if the task, but not the stimulus sequence, was altered. When the task was color discrimination or orientation discrimination with the same stimulus configuration as previously described, RTs became *shorter*, not longer, when targets were presented at the same location as in the previous trial. Note that all visual attributes including location were randomized here, thus any knowledge-based or higher-cognitive effect was not expected. We called this phenomena “Facilitation of Return (FOR)” (Tanaka and Shimojo, 1994; Tanaka and Shimojo, 1995b; Tanaka and Shimojo, 1996a; Shimojo et al., 1996a; Shimojo et al., 1996b). The inhibition/facilitation dissociation was attributed to task dependency: **spatial-orienting tasks** (detection, location discrimination, arm-reaching, and saccadic eye-movement tasks) led to inhibition (IOR), whereas **feature-discrimination tasks** (color, luminance, orientation, shape, and vernier discrimination tasks) led to facilitation (Tanaka and Shimojo, 1996a). The only variable accounting for the dissociation was the nature of the task, suggesting that separate visual mechanisms were at work depending on task. The dichotomy between inhibition and facilitation roughly corresponds to the neurophysiological dissociation between the so-called “where” versus

“what”, or “action” versus “recognition”, pathways in the visual processing stream (Ungerleider and Mishkin, 1982; Goodale and Milner, 1992). The former mainly contributes to the visual-motor link including eye/head movements and arm reaching (Tanaka and Shimojo, 1996a; Shimojo et al., 1996a), while the latter concerns processes for object recognition (Tanaka and Shimojo, 1995a; Tanaka and Shimojo, 1996b).

However, functional mechanisms characterizing the dissociation remain poorly understood. For example, does inhibition or facilitation occur cumulatively when a target is primed more than once at the same location? Is there a difference between inhibition and facilitation in this regard? Previous studies indicate that inhibition lasted no longer than two seconds of Response Stimulus Interval (RSI) (Kwak and Egeth, 1992; Tanaka and Shimojo, 1993). Recently, Pratt and Abrams (1995) showed that IOR exists only at the ‘most-recently-cued’ location. These results suggest that inhibition is generated by a transient type of attention related to the spatial-orienting mechanism in the visual-motor link (Rafal et al., 1989; Klein and Taylor, 1994; Tanaka and Shimojo, 1996a). In contrast, our previous data indicated that facilitation persisted longer than inhibition (more than 1.2 seconds of RSI; see experiment 1 and 3 in Tanaka and Shimojo, 1996a). Maljkovic and Nakayama (1994) found cumulative facilitation; RTs were successively reduced across trials when target color was repeated in a shape discrimination task (*repetition priming*). We found facilitation for similar pop-out stimuli and task (shape discrimination) (Tanaka and Shimojo, 1996a; Tanaka

and Shimojo, 1996b). These results suggest that facilitation either persists longer or accumulates more than inhibition, and that facilitation was generated by repetition.

In this study, we examined the cumulative nature of inhibition and facilitation by tracing RTs more than one previous trial, while keeping an identical set of stimuli. One particular question was whether inhibition and facilitation are cumulatively enhanced in successive trial sequences, which would provide a clue to clarify the functional mechanism of the dissociation in terms of its temporal characteristics. Another question we raised was whether inhibition and/or facilitation are selective to a certain relation between stimuli and task. Previous studies reveal that inhibition occurs in the location-related tasks (detection or location discrimination), whereas FOR occurs with stimuli and task in different visual attributes (Tanaka and Shimojo, 1996a, but see object-based IOR (Tipper and Bruce, 1991; Gibson and Egeth, 1994; Tipper et al., 1994)). Repetition effects (Maljkovic and Nakayama, 1994) occurred with a different stimuli-task relationship (color repetition effects in the shape discrimination task). Klein and Taylor (1994) argued that the IOR was associated with oculomotor processes, namely related to the response to the source of visual stimulation, indicating that IOR would be seen in spatial-orienting tasks, but not in non-spatial discrimination tasks (Klein and Taylor, 1994), relevant to (Kwak and Egeth, 1992; Terry et al., 1994). These results suggest some interaction between visual attributes and tasks (Tanaka and Shimojo, 1996b). To examine this, we decided to make extensive analyses by combining

various tasks and stimulus repetition sequences. Repetition effects were tested either in **1.** location, **2.** color, **3.** orientation, **4.** shape, **5.** or their combinations. Tasks (tested in separate sessions) were (a) simple detection, (b) location discrimination, (c) color discrimination, (d) orientation discrimination, or (e) shape discrimination. A set of experiments similar to our previous study was carried out (Tanaka and Shimojo, 1996a), using a simple target display (rectangle, experiment 1), color-defined pop-out (experiment 2), or orientation-defined pop-out (experiment 3) displays. We found a functional dissociation between inhibition and facilitation in terms of repetition selectivity to both attributes and tasks involved.

## **2 Experiment 1**

In the first experiment, a simple target display (rectangle) was used, which included the stimulus dimensions of location, color, and orientation at the same time. Several sub-experiments consisted of the experiment to test effects of different tasks.

### **2.1 Subjects**

Seven subjects participated in the experiment. Five naive subjects, unaware of the purpose of the experiment, were MIT undergraduate students (paid 5\$ per hour). Two non-naive subjects were the authors. All subjects had normal or corrected-to-normal visual acuity and normal color vision.

## 2.2 Stimuli and procedure

Stimuli and procedure were similar to our previous study (Tanaka and Shimojo, 1996a). A target (rectangle) was presented at different locations (either left or right), in different colors (either red or green), and at different orientations (either vertical or horizontal) in different temporal sequences (Fig. 1).

————— insert Fig. 1 about here —————

The target size was  $0.5^\circ \times 0.4^\circ$  of visual angle, its luminance  $6.4 \text{ cd/m}^2$  (hue: R (.555, .344) G (.320, .555), which was close to subjective equi-luminance). The fixation stimulus was a crossing,  $0.1^\circ \times 0.1^\circ$  in size. The distance between the fixation stimulus and the target was  $6.0^\circ$ . Background luminance was  $0.01 \text{ cd/m}^2$ . The stimuli were presented on a CRT display (Commodore 1840S; non-interlaced, frame frequency rate = 60Hz) controlled by a microcomputer (Commodore Amiga 1200). The sequence of each trial was as follows: first, the fixation appeared in the center of the screen for the duration of 150 msec (Fig. 1). Then the target appeared either on the top-left or top-right side of the fixation stimulus until a response was made. RT was measured as the time between the onset of the target and the onset of the response. As soon as the subject responded to the target, it disappeared. The fixation stimulus remained throughout the trial. After the randomized Response Stimulus Interval (RSI; 100, 300, 500, or 1200 msec), the next trial started. No feedback was given for error trials.



The target location (left or right), color (red or green), and orientation (vertical or horizontal) were all randomized on each trial, to minimize the *probability priming* effect (Tanaka and Shimojo, 1993). The subject engaged in four different tasks, in separate sessions: (1) the *simple detection* task, (2) the *location discrimination* task (between left and right), (3) the *color discrimination* task (between red and green), and (4) the *orientation discrimination* task (between vertical and horizontal). The stimuli, and their sequence, were generated by an identical method across all tasks, thus the only difference was the nature of the task. The subject was asked to make a two alternative-forced-choice (2AFC) judgment by pressing a button in all the discrimination tasks. In the simple detection task, only one (the left mouse) button was used. In the location discrimination task, a left (right) mouse-button press indicated the target appeared at the left (right) side of the fixation stimulus. The same two (left/right) buttons were pressed for the color discrimination task (to the red/green targets, respectively) and in the orientation discrimination task (to the vertically/horizontally elongated target, respectively). Each session consisted of six hundred forty trials, which took about 20 minutes to complete. A session consisted of four sub-sessions, and breaks were given between sub-sessions (overall three times). Repetition was counted from the beginning when each sub-session started. The order of sessions was randomized across subjects. Subject's head was stabilized by a chin rest. Viewing was binocular. Eye fixation was monitored in selected sessions with an eye tracker (Ober2, Permobil

Corp.). The viewing distance was 57 cm. Experiments were conducted in a completely dark environment. A practice session (100 trials) was conducted for each task before starting the experiment.

To investigate cumulative effects of repetition for each visual attribute, data were analyzed according to the order in repetition sequence for an individual attribute (location, color, or orientation). Data were further analyzed according to a combination of three attributes. RTs in error trials in discrimination tasks were eliminated from the data analysis. RTs below 100 msec and above 1,300 msec were also eliminated. Sessions where the error rate for discrimination exceeded 10% were eliminated as well.

## 2.3 Results

No sessions were excluded since all subjects exceeded the baseline of 90% of correct performance in the discrimination tasks. Average accuracy across seven subjects for each task was 97% in the location discrimination task, 96% in the color discrimination task, and 95% in the orientation discrimination task, respectively. Eye fixation was maintained within a limited space (less than  $0.5^\circ$  of visual angle from the fixation stimulus) during the session tested. Mean RTs were plotted as a function of a number of repetition *in location* (Fig. 2a), *in color* (Fig. 2b), and *in orientation* (Fig. 2c) to examine repetition effects in location, in color, and in orientation, respectively. Combination effects between the attributes were tested as well.

————— insert Fig. 2 about here —————

The first trial in each dimension sequence is labeled ‘0th’ of the number of repetition as there have been no repetitions in that dimension. This indicates a switch in each dimension. The repetition number the first indicates that stimuli were repeated only once and then switched in a particular dimension. In each graph, mean RTs for four different tasks (single detection, location discrimination, color discrimination, and orientation discrimination) were plotted separately. Baseline RT was calculated by averaging RTs of the first trials of each sub-session for seven subjects ( $n=7 \times 4$ ), which was 359 msec in the simple detection task, 453 msec in the location discrimination task, 710 msec in the color discrimination task, and 650 msec in the orientation discrimination task, respectively.

### **Location repetition effect**

Location repetition effects were tested by plotting Mean RTs against a number of repetition in location for each task. In the simple detection task and in the location discrimination task, mean RTs increased only at the first repetition in location. One way repeated measure of analysis-of-variance (ANOVA) revealed an increase of mean  $RTs \pm SE = +38 \pm 5$  msec ( $p < 0.001$ ) for detection, and  $+57 \pm 7$  msec ( $p < 0.001$ ) for location discrimination. The increase in RTs demonstrates *inhibition of return* (IOR;

Posner and Cohen, 1984). RTs gradually decreased to the initial level when location was repeated (difference between 0th and 6th repetition in sequence;  $10 \pm 21$  msec,  $p < 0.53$ ). This indicates that inhibition (IOR) was observed only in the first repetition sequence in location (Fig. 2a). The pattern was significantly different in the color- and in the orientation- discrimination tasks. The first repetition in location produced facilitation in RTs. One-way ANOVA revealed a mean RT reduction of  $+72 \pm 21$  msec ( $p < 0.001$ ) for color discrimination, and  $+81 \pm 13$  msec ( $p < 0.0001$ ) for orientation discrimination. The facilitation was *cumulative*, continued until at least the 6th repetition in sequence. The magnitude of maximum cumulative facilitation was  $+102 \pm 39$  msec ( $p < 0.001$ ) in the color discrimination task, and  $+112 \pm 21$  msec ( $p < 0.001$ ) in the orientation discrimination task (Fig. 2a). An extensive analysis revealed no effect of RSI except for the detection task (Table 1, see combination analysis). This indicates that facilitation is accumulated over time with repeated location (*location repetition effect*). When the elevation of overall RTs are taken into account, magnitude of inhibition was 12.5% in the simple detection task and 23% in the location discrimination task. The magnitude of facilitation was 16.7% in the color discrimination task and 14% in the orientation discrimination task.

### Color and orientation repetition effects

To test color- and orientation- repetition effects, mean RTs were plotted against a number of repetition in color and in orientation for each task (Figs. 2b and 2c). A

color repetition effect was observed only in the color discrimination task (Fig. 2b), until the 5th repetition in sequence (RT reduction from the 0th to the 5th;  $109 \pm 30$  msec,  $p < 0.01$ ). No color repetition effects were observed in other tasks, although there was a tendency of RT reduction at the 5th and the 6th repetition in the orientation discrimination task ( $p < 0.10$ ). An orientation repetition effect was observed only in the orientation discrimination task (Fig. 2c), although the effect was weaker. RTs reduced until the 3rd repetition in sequence ( $112 \pm 25$  msec,  $p < 0.001$ ), which saturated afterwards. There was a tendency of RT reduction in the color discrimination task until the 4th repetition in sequence ( $42 \pm 35$  msec,  $p < 0.15$ ). The magnitude of facilitation was 13% of overall RTs in color repetition (color discrimination task), and 16% in orientation repetition (orientation discrimination task) .

### Combination repetition effects

Combination repetition effects were tested between stimulus features of location, color, and orientation. The relationship between the previous and the present trial's location (same or different), color (same or different), and orientation (same or different) were examined simultaneously. There were 8 ( $=2^3$ ) combinations [i.e., (location, color, orientation) = (same, same, same), (same, same, different), etc]. A four-way ANOVA (**Table 1**) revealed no systematic interactions between location and color, location and orientation, and color and orientation in the simple detection task and

the location discrimination task (Fig.3, top two panels). Only the attribute of location (same/different) produced the significant main effect ( $p < 0.0001$  for detection,  $p < 0.0001$  for location discrimination) in RTs, indicating IOR. The variable of RSI was significant ( $p < 0.01$ ) only in the detection task (Table 1); there was a tendency that shorter RSIs yielded longer RTs for both same and different locations, suggesting some interference towards a detection process at shorter RSIs (Tanaka and Shimojo, 1996a). Combination effects were observed between location, color, and orientation in the color- and the orientation- discrimination tasks. Four-way ANOVA (**Table 1**) shows that overall RTs were shorter ( $p < 0.0001$ ) with location repetition (=same location), as compared to those without repetition (=different location). In addition, under the condition of location repetition (=same location), RTs were shorter ( $p < 0.05$ ) with color repetition (=same color) than without repetition (=different color), with an exception of the orientation discrimination task. Finally, RTs were the shortest when all attributes of location, color, and orientation were repeated (=the same location, the same color, and the same orientation) for color ( $p < 0.05$ ) and orientation ( $p < 0.05$ ) discrimination tasks. This demonstrates that repetition effects can be combined among the visual features of location, color, and orientation in the feature-discrimination tasks. This combination effect did not occur in the spatial-orienting tasks.

————— insert Fig. 3 about here —————

## 2.4 Discussion

We replicated the dissociation between inhibition (IOR) and facilitation in RTs depending on the different nature of the task; inhibition occurred in spatial-orienting tasks (simple detection and location discrimination), whereas facilitation was observed in feature-discrimination tasks (color and orientation discrimination), consistent with Tanaka and Shimojo (1996a). It was not the distinction between detection and discrimination tasks, but rather the nature of the task, that yielded the dissociation between inhibition and facilitation. Inhibition and facilitation showed different cumulative characteristics. Inhibition was observed only in the first trial of a repetition sequence, and persisted at most 1,600 msec, assuming the longest RSI (1,200 msec) and mean RTs (400 msec) are added. This is consistent with the results obtained by Pratt and Abrams (1995) and our previous data where inhibition disappeared at 2,000 msec of RSI (Tanaka and Shimojo, 1993). In contrast, facilitation persisted and accumulated up to the 6th repetition in location (more than 12 seconds). The difference supports the idea of a transient characteristic of inhibition (Pratt and Abrams, 1995; Tanaka and Shimojo, 1996a) and a sustained characteristic of facilitation (Tanaka and Shimojo, 1996a). Cumulative RT reduction was found in the color discrimination task when color was repeated, and in the orientation discrimination task with orientation repetition. This suggests a cumulative process of priming in a relevant task in each stimulus dimension. The task-relevant repetition was only observed in the feature-discrimination

tasks, but not in the spatial-orienting tasks. Combination repetition effects also occurred only in the feature discrimination tasks, but not in the spatial-orienting tasks. These results can be taken as another piece of evidence for the functional dissociation between location and feature with relevant tasks (Tanaka and Shimojo, 1996a).

### **3 Experiment 2**

In experiment 1, the target was defined by a rectangle against a blank background. In this experiment, the cumulative characteristics of inhibition and facilitation were tested using pop-out displays (Treisman and Galade, 1980). Pop-out displays can yield vigorous and parallel feature analyses across a large visual field (Julesz, 1981; Treisman and Galade, 1980). In the previous study, we used the color-defined pop-out display and found a similar type of dissociation between IOR and FOR as in the single target display (Tanaka and Shimojo, 1996a, experiment 4). Here, the critical question was whether transient and sustained types repetition effects occur in the pop-out display as well. We expect that pop-out displays produce transient inhibition for spatial orienting tasks and sustained facilitation for feature discrimination tasks, as occurred in the single target display.

#### **3.1 Subjects**

Six subjects [four naive and two non-naive (authors)] participated in the experiment.



All had normal or corrected-to-normal visual acuity and normal color vision.

### 3.2 Stimuli and procedure

We used color-defined pop-out stimuli similar to those used in our previous study (Tanaka and Shimojo, 1994, 1995a, 1996a). The target (diamond) was defined by color (red or green) which was different from that of distractors (green or red; the same shape, adopted from Maljkovic and Nakayama, 1994). Each diamond was cut off at either the top or the bottom. The size of the target and each distractor item was  $0.75^\circ \times 0.60^\circ$  of visual angle (Fig. 4).

————— insert Fig. 4 about here —————

The luminance of the target/distractor item was  $5.18 \text{ cd/m}^2$  when it was red, and  $12.6 \text{ cd/m}^2$  when it was green (hue: R(.555, .344), G(.320, .555)). The location of the target was randomized across trials between top-left and top-right of the fixation stimulus. The location of distractors and the color of the target were also randomized. The number of distractors was fixed at fifteen. There were catch trials (20% of the overall trials), where eight red and eight green items were presented at random locations. In this case, no target popped out and the subject should not respond. The catch trials were introduced to assure subjects to respond only to the pop-out target, but not to a local feature. Tasks were similar to those in experiment 1; (1) simple detection,

(2) location discrimination (either left or right), (3) color discrimination (either red or green), and (4) shape discrimination (either the top or the bottom of the target cut off). In discrimination tasks, the subject made a 2AFC judgment. In the case of shape discrimination, the subject had to judge whether the top or the bottom corner of the diamond-shaped target was cut off. The RTs accepted for analysis were between 100 msec and 2,000 msec. Otherwise, the stimuli, the procedures, and the analyses were the same as those in experiment 1.

### **3.3 Results**

No sessions were excluded since all subjects exceeded the baseline of 90% of correct performance in the discrimination tasks. Average accuracy across six subjects for each task was 96% in the location discrimination task, 94% in the color discrimination task, and 93% in the orientation discrimination task, respectively. As in experiment 1, we analyzed the data according to location repetition (Fig. 5a), color repetition (Fig. 5b), and shape repetition (Fig. 5c). Baseline RTs averaged across the first trials ( $n=6 \times 4$ ) in each sub-session were 517 msec in the simple detection task, 663 msec in the location discrimination task, 880 msec in the color discrimination task, and 960 msec in the shape discrimination task, respectively.

————— insert Fig. 5 about here —————

**Location repetition effect**

As is seen in Fig. 5a, IOR was observed in the spatial-orienting tasks, occurring only at the first repetition in location (RT reduction: one way ANOVA;  $-58\pm 10$  msec,  $p < 0.001$  for detection,  $-88\pm 12$  msec,  $p < 0.001$  for location discrimination). The inhibition (RT increase) was not cumulative and kept constant until the 4th repetition, decreasing to the initial level at the 5th repetition or later. In the color discrimination task, facilitation was repeated up to the 6th repetition (cumulative RT reduction:  $172\pm 37$  msec,  $p < 0.001$ ). In the shape discrimination task, facilitation was observed only in the 1st ( $109\pm 17$  msec) and the 6th ( $120\pm 69$  msec) repetition. The magnitude of IOR was almost identical to experiment 1. It was 13% of overall RT reduction in the detection task and 19% in the location discrimination task, compared with 12.5% and 23% in experiment 1, respectively. The magnitude of facilitation was relatively large. It was 25% of overall RT reduction in the color discrimination task, and about 24% in the shape discrimination task, compared with 16.7% and 14% in experiment 1, respectively.

**Color and shape repetition effects**

In terms of color repetition and shape repetition, results differed from those of experiment 1. RT reduction in color repetition was observed both in the color discrimination task (Fig. 5b, RT reduction from 0th to 7th;  $399\pm 35$  msec,  $p < 0.001$ )

and in the shape discrimination task (0th-5th;  $297 \pm 69$  msec,  $p < 0.01$ ). Facilitation was larger and more cumulative in shape repetition (Fig. 5c). RT reduction in shape repetition was maximum  $251 \pm 57$  msec (0th-6th,  $p < 0.001$ ) in the color discrimination task and  $659 \pm 96$  msec (0th-7th,  $p < 0.01$ ) in the shape discrimination task, respectively. Interestingly, there was also facilitation in the spatial-orienting tasks. RTs reduced when color was repeated in the detection task (overall reduction from 0th to 7th;  $157 \pm 64$  msec,  $p < 0.01$ ), as well as location discrimination task ( $249 \pm 78$  msec,  $p < 0.001$ ). RT reduction in shape repetition was also observed in the detection task (overall;  $138 \pm 29$  msec,  $p < .001$ ) and in the location discrimination task ( $245 \pm 72$  msec,  $p < 0.01$ ). The magnitude of color repetition effects was exaggerated, which was 46% reduction in the color discrimination task and 30% in the shape discrimination task, as compared with experiment 1 (13% for color discrimination). This was also true for shape repetition effects, which was 28% enhancement in the color discrimination task and 59% in the shape discrimination task, as compared with experiment 1 (16% for orientation discrimination).

### **Combination repetition effects**

The same combination analysis as the single target display (experiment 1) was applied for the color-defined pop-out display. Statistical analysis (four-way ANOVA) is shown in Table 2. In general, when location repeated as for one previous trial (=same location), RTs were longer in the spatial-orienting tasks, representing IOR (top two

panels in Fig. 6), whereas RTs were shorter in the feature-discrimination tasks (=facilitation). Interestingly, when location repeated (=same location) as well as color repeated (=same color), RTs were shorter in the spatial-orienting tasks (top panels) as well as in the feature-discrimination tasks (bottom panels). This was also true when location and shape repeated (=same location and same shape) for all tasks except for color discrimination. The shortest RTs were observed when location, color, and shape were all repeated in the feature discrimination tasks. These results indicate that repetition effects were combined between color and shape both in the feature-discrimination tasks and in the spatial-orienting tasks. Repetition effects were combined between location, color, and shape in the feature-discrimination tasks. There were significant effects of RSI in the location discrimination task ( $p < 0.001$ ) and the shape discrimination task ( $p < 0.05$ ). For location discrimination, longer RSIs ( $< 500$  msec) tended to yield longer RTs when location was repeated, whereas for shape discrimination longer RSIs ( $< 500$  msec) yielded shorter RTs, possibly reflecting lateral interaction enhancing both inhibition and facilitation at longer delays (see discussion).

————— insert Fig. 6 about here —————

### 3.4 Discussion

The overall tendency was similar to that in experiment 1. There was clear dissociation between the spatial-orienting tasks (simple detection or location discrimination) and the feature (color or shape) discrimination tasks in location repetition (Fig. 5a), consistent with our previous results (Tanaka & Shimojo, 1994, 1996a). The magnitude of inhibition and facilitation were exaggerated, as well as their temporal influence ranges (numbers of repetition) prolonged, presumably due to lateral interactions between adjacent spatial filters (Rubenstein and Sagi, 1990; Polat and Sagi, 1993; Tanaka and Sagi, 1998). These indicate the availability of output from the global texture analysis for the IOR as well as the FOR mechanisms, suggesting that low-level visual processing is involved for the IOR and the FOR (Julesz, 1981; Julesz, 1986; Sagi and Julesz, 1985; Rubenstein and Sagi, 1990).

There was also ‘task-dependent’ and ‘feature-selective’ repetition effects in color (color repetition effect in the color discrimination task, Fig. 5b) and in shape (shape repetition effect in the shape discrimination task, Fig. 5c). The magnitude of color repetition effects and that of shape repetition effects were both enhanced compared with the single target display, suggesting an involvement of global texture analysis in the color/shape repetition effects. The differences between the current experiment and experiment 1 are worth noting. Repetition effects were observed when stimulus and task dimensions are different between color and shape (i.e., the color repetition

effect in the shape discrimination task), suggesting *task-irrelevant* repetition effects. These task-irrelevant effects might be caused by a stimulus-driven factor in pop-out stimuli, rather than from the task demands. The other difference between experiments 1 and 2, namely facilitation by repetition of features even in the spatial-orienting tasks, also suggests stimulus-driven factors such as feature selectivity of neural responses in the cortex (Hubel and Wiesel, 1962; Livingstone and Hubel, 1987; Zeki and Ship, 1988). Here we propose a “feature activation” account, assuming following aspects: (1) **task-relevant** features (color or shape) are activated in both the single-target and the pop-out displays under an active top-down influence. (2) Features critical to pop-outs are activated pre-attentively or passively in a **stimulus-driven** manner (**task-irrelevant** activation). (3) Both types of activation operate simultaneously, leading to facilitation or reduction in RTs with repetition. This can explain most of facilitatory effects observed in the current experiment, including the facilitation in the spatial-orienting tasks. This also explains different pattern of results in the combination analysis: combination repetition effects occurred not only in the feature-discrimination tasks, but also in the spatial-orienting tasks, which can be attributed to stimulus-driven activation by task-irrelevant features (pop-out display).

## 4 Experiment 3

In experiment 2, pop-out displays were defined by color. There was a task-irrelevant (stimulus-driven) repetition effect in the color-defined pop-out display. Then, one may easily expect an orientation-defined repetition effect by an orientation-defined pop-out display. This is because the pop-out display itself may bias the response in a task-irrelevant (stimulus-driven) manner from orientation domain, which is another stimulus-driven feature in early vision (Treisman and Galade, 1980; Julesz, 1981; Julesz, 1986; Sagi and Julesz, 1985; Rubenstein and Sagi, 1990). The current experiment, using an orientation-defined pop-out display, was conducted for this reason.

### 4.1 Subjects

Six subjects [four naive and two non-naive (authors)] participated in the experiment. All subjects had normal or corrected-to-normal visual acuity and normal color vision.

### 4.2 Stimuli and Procedure

The target (line element) was defined by orientation (vertical or horizontal), which was orthogonal to that of distractors (Fig. 7).

————— insert Fig. 7 about here —————

The size of the target/distractor was  $0.75^\circ \times 0.60^\circ$  of visual angle. The distance between the target and the fixation stimuli was  $5.20^\circ$ . The color of the target/distractor bars



was either red or green (randomized). The luminance of the target/distractor item was  $5.18 \text{ cd/m}^2$  when it was red, and  $12.6 \text{ cd/m}^2$  when it was green (hue: R(.555, .344), G(.320, .555)). The luminance of background was  $0.01 \text{ cd/m}^2$ . The location of distractors and the color of target and distractors were randomized across trials. The number of distractors was fixed at forty eight. The stimuli, the procedure, and the analysis were otherwise the same as experiment 2.

### 4.3 Results

No sessions were excluded since all subjects exceeded the baseline of 90% of correct performance in the discrimination tasks. Average accuracy across six subjects was 96% in the location discrimination task, 94% in the color discrimination task, and 92% in the orientation discrimination task, respectively. Mean RTs were plotted against a number of repetition in location (Fig. 8a), in color (Fig. 8b), and in orientation (Fig. 8c). Baseline RTs averaged across the first trials ( $n=6 \times 4$ ) were 487 msec in the simple detection task, 558 msec in the location discrimination task, 917 msec in the color discrimination task, and 907 msec in the orientation discrimination task, respectively.

————— insert Fig. 8 about here —————

#### Location repetition effect

Inhibition (IOR) was observed in the spatial-orienting tasks, occurring only at the first repetition in location (RT reduction: one way ANOVA;  $-40\pm 11$  msec,  $p < 0.01$  for detection,  $-65\pm 11$  msec,  $p < 0.001$  for location discrimination). The inhibition (RT increase) in the location discrimination task kept constant until the 4th repetition, and decreased to the initial level. In the detection task, the RTs kept constant up to the 6th repetition. In the color discrimination task, facilitation accumulated up to the 5th repetition (cumulative RT reduction:  $246\pm 44$  msec,  $p < 0.001$ ). Facilitation accumulated in the orientation discrimination task up to the 7th repetition ( $276\pm 57$  msec,  $p < 0.001$ ), except the 4th repetition ( $p < 0.23$ ). The magnitude of location repetition effects was 27% of overall RTs in the color discrimination task, and 35% in the shape discrimination task, slightly enhanced than those in the color-defined pop-out display (25% and 24% respectively). The magnitude of IOR was about 16% in the detection task, and 20% in the location discrimination task, similar to the color-defined pop-out display (experiment 2).

### **Color and orientation repetition effects**

Color repetition effects were observed (in Fig. 8b) both in the color discrimination task (cumulative RT reduction up to the 5th sequence:  $118\pm 78$  msec,  $p < 0.001$ ) and in the orientation discrimination task (up to the 6th sequence:  $123\pm 58$  msec,  $p < 0.01$ ). There were no clear color repetition effects in the spatial-orienting tasks, except for the 5th-7th repetition in the detection task. Orientation repetition effects were also

observed (in Fig. 8c) both in the color discrimination task (cumulative RT reduction:  $163 \pm 68$  msec,  $p < 0.01$ ) and in the orientation discrimination task ( $115 \pm 47$  msec,  $p < 0.01$ ). The magnitude of color repetition effects was about 15% in the color discrimination task, and about 16% in the orientation discrimination task, which are smaller than experiment 2 (46% and 30%, respectively). The magnitude of orientation repetition effects was about 27% in the color discrimination task, and about 13% in the orientation discrimination task, which are also smaller than experiment 2 (28% and 56%, respectively).

### **Combination repetition effects**

The same combination analysis as in experiments 1 and 2 was applied for the orientation-defined pop-out display (4-way ANOVA, Table 3). Similar tendencies to experiment 2 were found in this experiment. When location repeated (=same location), RTs were longer in the spatial-orienting tasks (IOR; top two panels in Fig. 9), whereas RTs were shorter in the feature discrimination tasks (=facilitation). RTs were shorter when orientation repeated, independent of location repetition in the spatial-orienting tasks. RTs were shorter when both location and color repeated (=same location and same color), and when location and orientation repeated (=same location and same orientation) in the feature discrimination tasks (bottom two panels in Fig. 9). Eventually, RTs were shortest when location, color, and orientation repetition were all combined

in the feature discrimination tasks. There were significant RSI effects (Table 3) in the simple detection task ( $p < 0.0001$ ) and in the location discrimination task ( $p < 0.01$ ). In either case, longer RSIs ( $>500$  msec) tended to yield longer RTs suggesting some temporal dynamics of lateral interaction (Tanaka and Sagi, 1998).

————— insert Fig. 9 about here —————

#### **4.4 Discussion**

The pattern of results (Fig. 8) was similar to experiment 2. That is; (1) inhibition (IOR), observed in the spatial-orienting tasks with the first location repetition, did not increase with number of repetitions. In contrast, the facilitation that was observed in the color- and the orientation- discrimination tasks, continued with increased number of repetitions (until the 7th repetition). (2) Color repetition effects in the color discrimination task, and orientation repetition effects in the orientation discrimination task were found, whereas no repetition effect in color occurred in the spatial-orienting tasks (Fig. 6b). These repetition effects possibly occurred due to the task-relevant factor (stimulus-task contingency). (3) Color repetition effects in the orientation discrimination task, and orientation repetition effects in the color discrimination task were observed. Also, orientation repetition effects occurred in the spatial-orienting tasks. These repetition effects possibly occurred due to the pop-out bias of orientation (stimulus-driven factor). (4) Combination analysis yielded the combination repeti-

tion effects between location and orientation in the spatial-orienting tasks, and the combination effects between location, color, and orientation repetition. The location-orientation combination effect probably occurred due to both the IOR mechanism and stimulus-driven pop-out bias. The other combination effects possibly occurred due to the task-relevant factor (stimulus-task contingency) and the pop-out bias.

These results suggest a common mechanism for pop-out displays that produces (1) the dissociation between inhibition (IOR) and facilitation in location repetition, (2) the task-relevant repetition effects for color or for orientation, and (3) the stimulus-driven (=pop-out relevant) repetition effects for orientation, indicating that visual performance can be modified by top-down activation of task-relevant features, as well as stimulus-driven activation by pop-out relevant features.

## **5 General Discussion**

The purpose of this study was to investigate the accumulation of inhibition (IOR) and facilitation, as well as to examine attribute-selective characteristics for the repetition effects. We found a selective modulation in RTs both from stimuli and task demands.

## 5.1 Modulation by stimuli and tasks

There was an interaction between visual attributes and tasks (**Table 4**). Repetition in location produced inhibition (IOR) in the spatial-orienting tasks (detection and location discrimination), whereas it produced cumulative facilitation in the feature (color, orientation, or shape) discrimination tasks. Repetition in color produced cumulative facilitation in the color discrimination task for all displays (*task relevant* repetition effects), as well as in the orientation discrimination task in two pop-out displays (experiments 2). Similar facilitation was observed with orientation repetition (experiment 3). There were also *stimulus driven* repetition effects in the pop-out displays, producing pop-out relevant repetition effects even in the spatial-orienting tasks (**Table 5**). Repetition in shape might be different from that in orientation. The magnitude of the shape repetition effects (Fig. 5c) was much larger than the orientation repetition effects (Fig. 8c). Repetition effects in color and in shape in the spatial-orienting tasks were also enhanced compared with the orientation-defined pop-out display (experiment 3), suggesting an involvement of higher-level recognition processes for shape in experiment 2. When the pop-out dimension matches the task (i.e., color/color), one may interpret the fact that subjects made the correct response (red) either because they found the target (red) or because they noted the relatively homogeneous distractor color (green) and made the opposite response. The second interpretation was possible because target present arrays always involved a homogeneous distractor array with a

singleton target. This possibility, however, seems less likely because if the response opposite to instruction is made, it would require more attentional load, yielding longer RTs and/or higher error rates compared with the other (shape) discrimination task, which was not the case (RTs were shorter and error rates were virtually identical). There was no object-based inhibition by repetition, presumably because targets static and stationary characteristic (Tipper and Bruce, 1991; Gibson and Egeth, 1994; Tipper et al., 1994). Furthermore, combination analysis shows that (1) when the task is classified into spatial-orienting tasks, the condition showing inhibition (at the same location) are generally less sensitive to identify targets with respect to the previous target (orientation/color repetition), as compared to the different location conditions. (2) When the task is classified into feature discrimination tasks, the condition showing facilitation (at the same location) are generally more sensitive to identify repetitions than the different location conditions. These results demonstrate a double dissociation selective to both the attributes and the tasks involved; location versus other visual features (color, orientation) as for attributes, and spatial-orienting tasks versus feature-discrimination tasks, as for task demands. Performance was modified in a *stimulus-driven* (bottom-up) manner by the pop-out displays, and at the same time modified in a *task-dependent* (top-down) manner by operating tasks. The dissociation is consistent with findings that IOR was only observed in the spatial-orienting tasks but not in feature-discrimination tasks (Kwak and Egeth, 1992; Klein and Tay-

lor, 1994), as well as facilitation observed in feature-discrimination tasks such as color discrimination (Maljkovic and Nakayama, 1994), shape discrimination (Lambert and Hockey, 1986), and letter discrimination (Terry et al., 1994). Taken together, these results suggest multi-dimensional and multi-level aspects of attention between location and other visual features (Lambert and Hockey, 1986; Kwak and Egeth, 1992; Klein and Taylor, 1994).

## 5.2 Task dependency

Combination of task and visual attributes produced either transient inhibition or sustained (cumulative) facilitation (**task dependency**). Here, it is important to note that this task dependency differs in function from higher cognitive processes such as decision making (Keele, 1973; Jacoby and Craik, 1979), knowledge-based anticipation (Posner, 1980), expectation (Hikosaka et al., 1993), or ‘probability priming’ (Tanaka and Shimojo, 1993). These other processes involve more complex and larger-scale cognitive operations. Our tasks here assume an involvement of relatively simpler operations for selecting a specific visual attribute (i.e. location) from within different dimensions. To account for the stimulus-task modulated repetition effects, we propose a mechanism that operates in the two following ways; (1) it segregates visual information into each visual feature (such as location, color, orientation, binocular disparity, direction of motion, etc) in an independent and parallel manner (Hubel and Wiesel, 1962; Livingstone



and Hubel, 1987; Fellman and VanEssen, 1991; Marr, 1982). (2) These bottom-up signals are modified by a selective top-down process of task operation (Tanaka and Shimojo, 1996b). If a task is selected to perform one specific attribute (i.e. color discrimination task for the attribute of color), cumulative facilitation is observed within a specific stimulus dimension (=color repetition effects). The process operates as if the visual system is ‘tuned’ to a specific visual attribute or module (=color), by a specific task demand (=color discrimination). The output of the tuning operation would be enhancement or suppression of the module output, depending on the combination of task and attribute. Similar modifications of ‘top-down’ process towards a selective visual module was found in neurophysiological studies. Neuronal activities in V4 and/or IT in primates were modified by competitive processes of attention (Moran and Desimone, 1985) and short-time memory (Miller et al., 1991; Miller and Desimone, 1994).

In our previous study (Tanaka and Shimojo, 1996b), correlation between inhibition/facilitation dissociation and the neurophysiological segregation of “where” versus “what”, or “action” versus “recognition” pathways (Ungerleider and Mishkin, 1982; Goodale and Milner, 1992) was argued. In this study, we found an additional dissociation of temporal characteristics: inhibition operates *transiently* (a few seconds), whereas facilitation operates in a *sustained* and *cumulative* manner (more than 10 seconds). This suggests a segregation in terms of temporal properties between the two visual functions. The transient property may be appropriate for relatively fast

spatial-orienting processes in various visual-motor tasks (eye movements, head movements, and arm-reaching) (Tanaka and Shimojo, 1996a; Shimojo et al., 1996a), whereas cumulative facilitation may be suited to time-consuming visual recognition processes (color, orientation, shape, luminance, and vernier discrimination; Tanaka and Shimojo, 1996a). The transient/sustained characteristics are consistent with previous findings concerning visual attention by Nakayama and Mackeben (1989) and by Hikosaka et al. (1993), although our time course was relatively long (second order) compared with theirs (50-500 msec), suggesting activation of short-term visual memory. As for combination effects, Tanaka et al. (1991, 1993) reported a specific columnar structure in the inferotemporal cortex (IT), using single cell recording in monkeys, wherein neurons responded to the specific combination of color and orientation (i.e. red **and** horizontal *lips*) (Tanaka et al., 1991; Tanaka, 1993). This is relevant to our combination repetition effects between color and orientation (or shape). Recently, Sereno and Maunsell (1998) found that neurons in primate posterior parietal cortex (the “where” pathway) show sensory shape selectivities to simple, two-dimensional geometric shapes while the animal performs a simple fixation task. These results demonstrate that units in posterior parietal cortex contribute to shape selectivity equivalent to any shown in the ventral (“what”) pathway. This processing of shape (“what”) in the “where” pathway is relevant to our combination repetition effects between location and feature (color, orientation, or shape).

### 5.3 Repetition facilitation

In cognitive psychology, Keele (1973) argued for response repetition effects, whereby the response selection stage was *bypassed* and the previous response executed when observers notice that present stimulus was identical to the preceding one. Jacoby and Craik (1979) proposed a similar mechanism noting that after solving a complex cognitive operation such as calculating multiplication, when it is repeated on the subsequent trial, the previous answer will be recalled instead of computing the answer anew, if the subject realizes that the problem is identical. In other words, less “cognitive effort” was required with repetition. This mechanism seems relevant to the processes occurring in our feature-recognition tasks where relatively heavy attention was loaded compared with the spatial-orienting tasks, implying similar computational rules producing our repetition effects. While Keele (1973) and Jacoby and Craik (1979) suggested that repetition facilitation occurs at higher-cognitive levels such as decision diagnostic or strategy stages, we argue that our effects occurred relatively lower levels of processing stream. Our results show that inhibition occurred solely based on location, whereas facilitation occurred with a specific combination between tasks and visual features. This suggests that these effects do not occur in a single stage of response execution (Simon et al., 1981; Keele, 1973), but rather occur several different stages between stimulus-selection (perception) and response-execution (sensory-motor) stages. We consider two possibilities for such stages. One candidate is a stimulus identification stage where

different *perceptual* decision-making is employed. Since the tasks carried out in our study were detection or discrimination tasks of relatively simple visual features (location, color, orientation, or shape), it seems likely that computation was carried out within visual processing streams depending on tasks. Indeed, some neurophysiological studies indicate attentional effects in the extra-striate cortex (V4) for shape discrimination (Moran and Desimone, 1985) and in the middle temporal area (MT) for motion-direction discrimination (Treue and Maunsell, 1996). In contrast, other studies in humans (Courtney et al., 1997) and in monkeys (Wilson et al., 1993) demonstrate activations of higher cortical areas (such as pre-frontal cortex) with more demanding tasks (such as delayed matching-to-sample task), consistent with our theory. Facilitation and inhibition in the pop-out display point to an association of repetition effects with early visual processing stages (such as V1 or V2) (Knierim and VanEssen, 1992; Lamme, 1995; Zipser et al., 1996), suggesting an involvement of top-down attention to early vision (Motter, 1993; Tanaka and Shimojo, 1996b; Tanaka and Sagi, 1998). Another candidate of the operating stage is a ‘response selection stage’ (McCann and Johnston, 1992; Pashler and Johnston, 1992), whereby selection by a set of stimuli is made for the specific response according to a stimulus-response “translation rule”, generating ‘attentional bottleneck’ before the higher-level decision stage. Assuming that repetitive operation of this rule can decrease attention load, responses may be facilitated with repeating tasks. In this case, different types of coding rule should be

necessary to independently produce inhibition and facilitation. Both accounts can possibly fit the data shown in this study. Further research will be needed to distinguish these possibilities.

In summary, we found inhibition and facilitation in reaction time using a repetition priming paradigm. Inhibition disappeared transiently, whereas facilitation persisted in a sustained and cumulative manner. Both were modulated simultaneously by operating tasks and by the stimuli used. The results demonstrated functional dissociation between the spatial-orienting mechanism and the feature-analysis mechanism, as well as its selective, top-down modulation by short-term memory in the distinctive visual pathways.

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**Figure Captions****Figure 1**

Stimulus sequence for the single target experiment. The target was randomized in terms of location (left/right), color (red/green), and orientation (vertical/horizontal) across trials. Response Stimulus Interval (RSI) was also randomized among 100, 300, 500, and 1200 msec.

**Figure 2**

Results of the single target experiment. Mean RT is plotted as a function of (a) the number of repetition in location, (b) in color, and (c) in orientation. In each graph, results in four different tasks are shown in different curves: thin dot curve with filled circle; the simple detection task, thin curve with opaque circle; the location discrimination task, thick curve with upward triangle; the color discrimination task, and thick curve with downward triangle; the orientation discrimination task. The notation of this and successive graphs in figure 4 and 6 were the same across all the results of location, color, and orientation (shape) repetition. Vertical bars in this and successive graphs indicate standard errors.

**Figure 3**

Results of the combination repetition effects in the single target experiment. The top two panels show bar-chart results for the spatial-orienting tasks (top-left (a), simple detection, top-right (b), location discrimination). The bottom two panels show those for the feature

discrimination tasks (bottom-left (c), color discrimination, bottom-right (d), orientation discrimination). Within each panel, RTs for different/same locations as for the previous target location were classified into four types of bars of same or different, color and orientation combinations. In this and the next graphs, a light gray bar represents the mean RT for the combination of different color and different orientation. A middle gray bar, different color and same orientation, and a dark gray bar, same color and different orientation, and a hatched black bar, same color and same orientation.

**Figure 4**

A sample stimulus of the color-defined pop-out display. The target is defined by color which differs from that of distractors. The size of target/distractors were not in scale in this figure. Each diamond was chopped off at either top or bottom. Location (top left/top right), color (red/green) and shape (top/bottom chopped) of the target, location, color, and shape of distractors, and RSIs (100/300/500/1200 msec) are all randomized.

**Figure 5**

Results of the color-defined pop-out display. Mean RT is plotted as a function of number of repetition (a) in location, (b) in color, and (c) in shape. The results in four different tasks (detection, location/color/shape discrimination) are shown in different curves.

**Figure 6**

Results of the combination effects of the color-defined pop-out display. The format is the same as Figure 3.

**Figure 7**

A sample stimulus of the orientation-defined pop-out display. The target is defined by orientation which differs from that of distractors (all orthogonal to the target). The size of target/distractors were not in scale in this figure. Target's location (left/right), color (red/green), orientation (vertically/horizontal), distractor's color (red/green), location, and RSIs (100/300/500/1200 msec) were all randomized.

**Figure 8**

Results of the orientation-defined pop-out display. Mean RT is plotted as a function of number of repetition (a) in location, (b) in color, and (c) in orientation. The results in four different tasks (detection, location/color/orientation discrimination) are shown in different curves.

**Figure 9**

Results of the combination effects of the orientation-defined pop-out display. The format is the same as Figure 3.

**Table Captions****Table 1**

Combination analysis for each task and each stimulus dimension for the single target display. Data were analyzed with a four-way repeated measures analysis of variance (ANOVA) ( $Location \times Color \times Orientation \times RSI$ ) for each sub-experiment. Only the main effects and interaction that have turned out to be significant were listed here. Statistical significance at 5% level is indicated by \*, and that at 1% level is indicated by \*\*.

**Table 2**

Combination analysis (the 4-way ANOVA) for the color-defined display. Statistical significance at 5% level is indicated by \*, and that at 1% level is indicated by \*\*.

**Table 3**

Combination analysis (the 4-way ANOVA) for the orientation-defined display. Statistical significance at 5% level is indicated by \*, and that at 1% level is indicated by \*\*.

**Table 4**

Summary of results in all the experiments. IOR occurred in the spatial orienting tasks (simple detection, location discrimination), whereas repetition priming occurred in the feature discrimination tasks (color discrimination and orientation discrimination). “\*” indicates that

the effect was only observed in the pop-out displays.

**Table 5**

Summary of combination analysis results in all experiments. Combined repetition effect of location, color, and orientation (or shape) was shown only in the feature tasks, but not in the spatial-orienting tasks. Note the general tendency of color repetition effect for the color-defined pop-out display and orientation repetition effect for orientation-defined pop-out display, representing the task-irrelevant (stimulus driven) repetition effects.

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| Task-factor                | F value | Pr > F   |
|----------------------------|---------|----------|
| Simple detection           |         |          |
| Location                   | 10.59   | 0.0001** |
| RSI                        | 5.77    | 0.01**   |
| Location discrimination    |         |          |
| Location                   | 15.99   | 0.0001** |
| Color discrimination       |         |          |
| Location                   | 13.31   | 0.0001** |
| Color                      | 5.07    | 0.05*    |
| Orientation discrimination |         |          |
| Location                   | 13.31   | 0.0001** |
| Orientation                | 4.44    | 0.05*    |
| Color x Orientation        | 4.08    | 0.05*    |

Table 1: single target display

Tanaka &amp; Shimojo

| Task-factor             | F value | Pr > F   |
|-------------------------|---------|----------|
| Simple detection        |         |          |
| Location                | 7.08    | 0.01*    |
| Color                   | 17.77   | 0.0001** |
| Shape                   | 17.82   | 0.0001** |
| Location x Color        | 6.01    | 0.05*    |
| Location x Shape        | 5.88    | 0.05*    |
| Color x Shape           | 7.49    | 0.01*    |
| Location xColor xShape  | 4.44    | 0.05*    |
| Location discrimination |         |          |
| Location                | 11.51   | 0.001**  |
| Color                   | 11.39   | 0.001**  |
| Shape                   | 7.46    | 0.01*    |
| RSI                     | 12.00   | 0.001**  |
| Location x Color        | 7.42    | 0.01*    |
| Location x Shape        | 7.42    | 0.01*    |
| Color x Shape           | 5.62    | 0.05*    |
| Color x RSI             | 5.29    | 0.05*    |
| Color discrimination    |         |          |
| Location                | 13.26   | 0.0001** |
| Color                   | 19.41   | 0.0001** |
| Shape                   | 9.03    | 0.002**  |
| Location x Shape        | 6.13    | 0.05*    |
| Color x Shape           | 6.78    | 0.01*    |
| Location xColor xShape  | 6.78    | 0.01*    |
| Shape discrimination    |         |          |
| Location                | 5.21    | 0.05*    |
| RSI                     | 3.98    | 0.05*    |
| Location x Color        | 4.44    | 0.05*    |
| Color x Shape           | 4.40    | 0.05*    |
| Location xColor xShape  | 8.51    | 0.05*    |

Table 2: color-defined pop-out display



| Task-factor                | F value | Pr > F   |
|----------------------------|---------|----------|
| Simple detection           |         |          |
| Location                   | 10.14   | 0.001**  |
| Color                      | 9.35    | 0.01*    |
| Orientation                | 12.89   | 0.001**  |
| RSI                        | 17.18   | 0.0001** |
| Location x Color           | 9.35    | 0.01*    |
| Location x Orientation     | 7.70    | 0.01*    |
| Location xColor xOrient.   | 4.28    | 0.05*    |
| Location discrimination    |         |          |
| Location                   | 8.51    | 0.001**  |
| Color                      | 13.14   | 0.001**  |
| Shape                      | 24.05   | 0.0001** |
| RSI                        | 7.17    | 0.01*    |
| Color x Orientation        | 10.24   | 0.01*    |
| Color discrimination       |         |          |
| Location                   | 4.23    | 0.05*    |
| Orientation                | 4.12    | 0.05*    |
| Orientation discrimination |         |          |
| Location                   | 13.67   | 0.001**  |
| Color                      | 6.98    | 0.01*    |
| Orientation                | 5.07    | 0.05*    |
| Location x Color           | 4.05    | 0.05*    |
| Color x Orientation        | 5.08    | 0.05*    |

Table 3: orientation-defined pop-out display

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**+** : cumulative facilitation

**-** : inhibition, \* only for popout

| task<br>display    | simple<br>detection | location<br>discrim. | color<br>discrim. | orient.<br>(shape) |
|--------------------|---------------------|----------------------|-------------------|--------------------|
| single<br>target   | -                   | -                    | +                 | +                  |
| color<br>pop-out   | -                   | -                    | +                 | + *                |
| orient.<br>pop-out | -                   | -                    | + *               | +                  |

**Table 4**

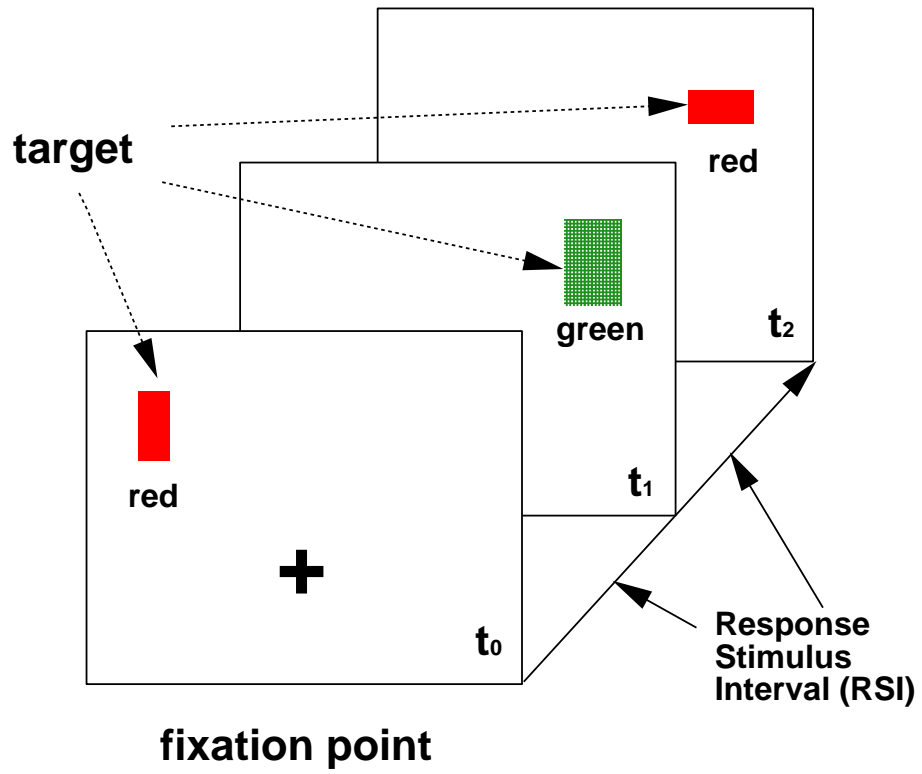
Tanaka & Shimojo

**+** : combination repetition  
**color** : color repetition  
**orient.** : orient. repetition

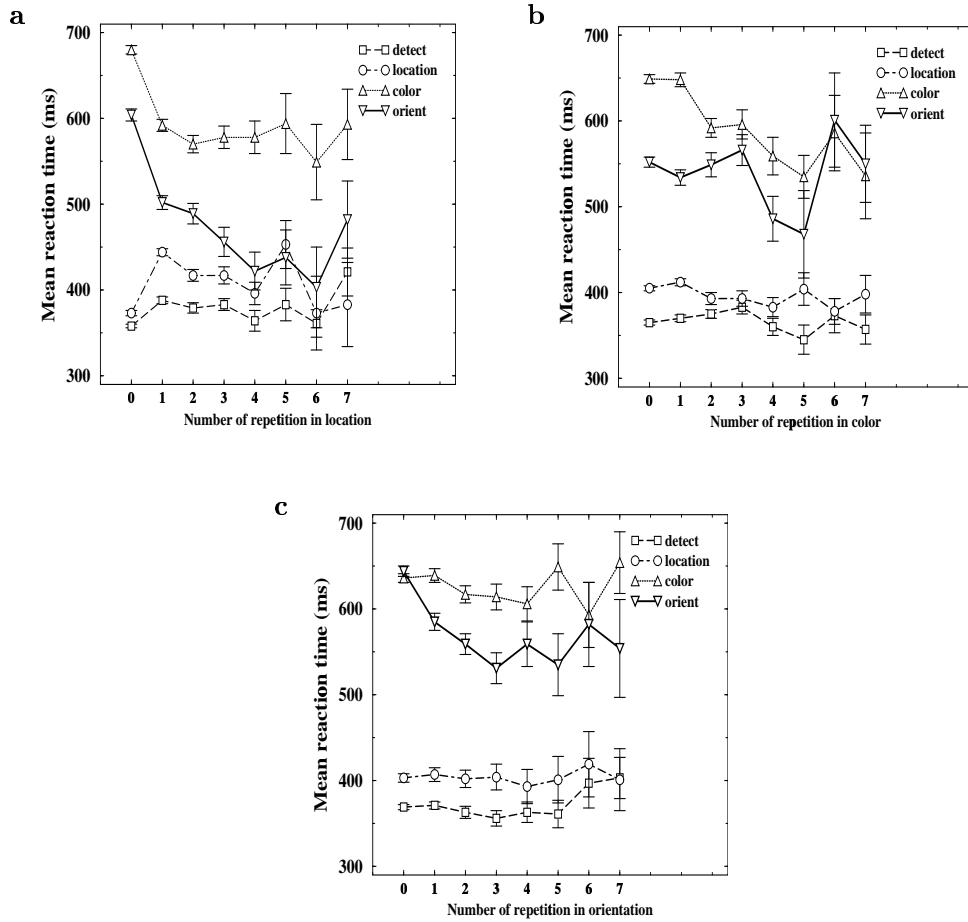
| <b>task</b><br><b>display</b>    | <b>simple</b><br><b>detection</b> | <b>location</b><br><b>discrim.</b> | <b>color</b><br><b>discrim.</b> | <b>orient.</b><br><b>discrim.</b> |
|----------------------------------|-----------------------------------|------------------------------------|---------------------------------|-----------------------------------|
| <b>single</b><br><b>target</b>   | <b>n.s.</b>                       | <b>n.s.</b>                        | <b>+</b>                        | <b>+</b>                          |
| <b>color</b><br><b>pop-out</b>   | <b>color</b>                      | <b>color</b>                       | <b>color</b>                    | <b>+</b>                          |
| <b>orient.</b><br><b>pop-out</b> | <b>orient.</b>                    | <b>orient.</b>                     | <b>+</b>                        | <b>+</b>                          |

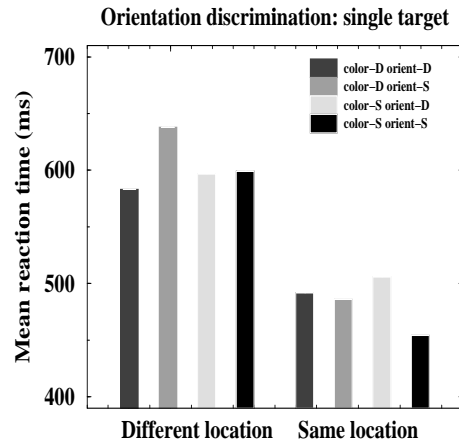
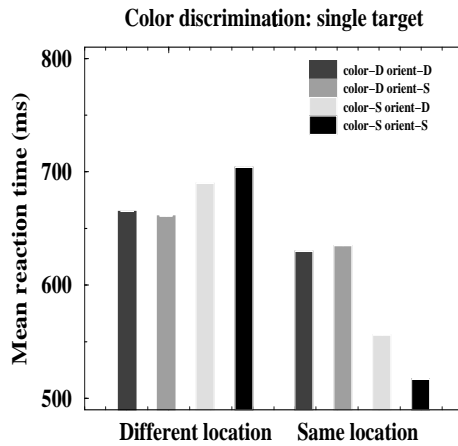
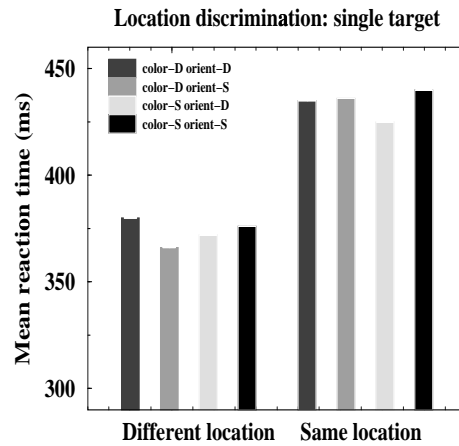
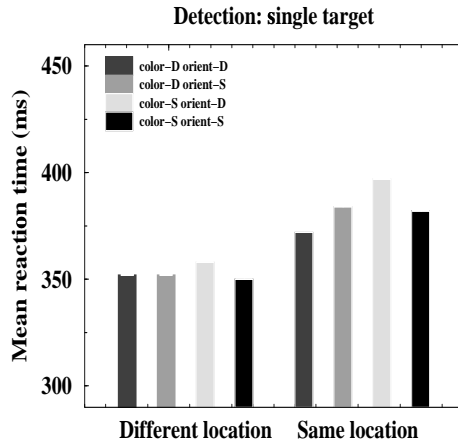
Table 5

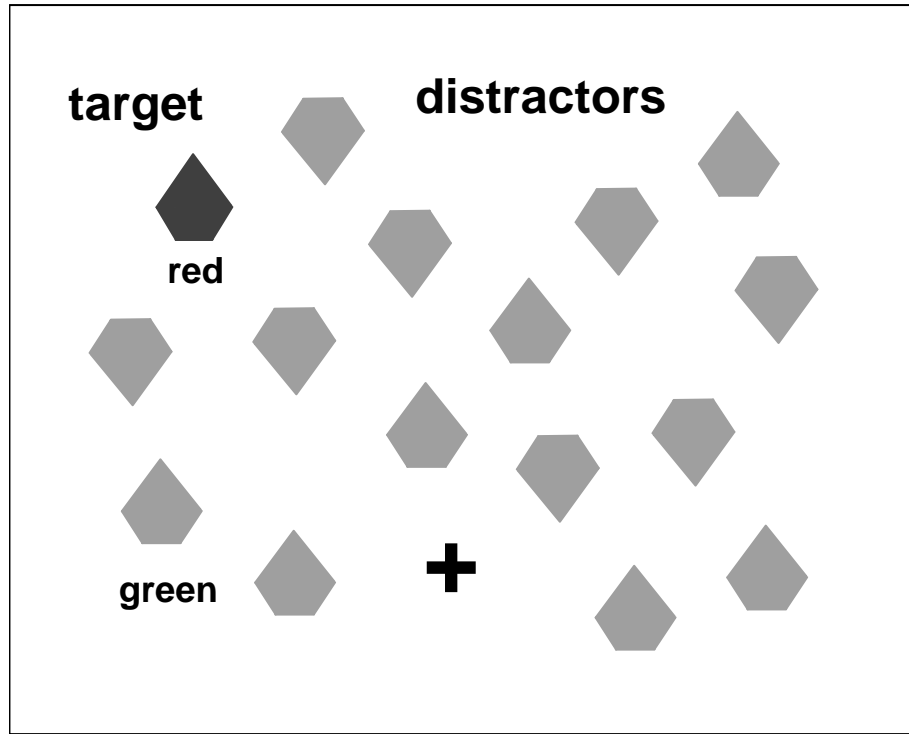
Tanaka &amp; Shimojo



Display: single target

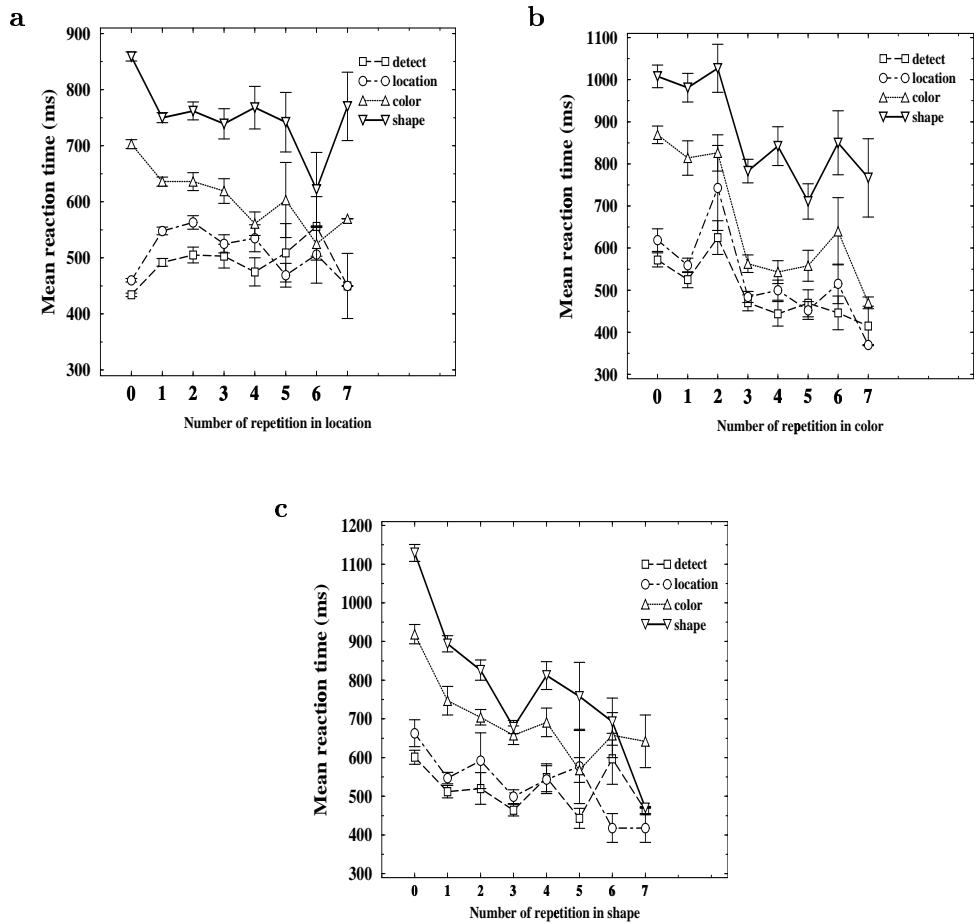




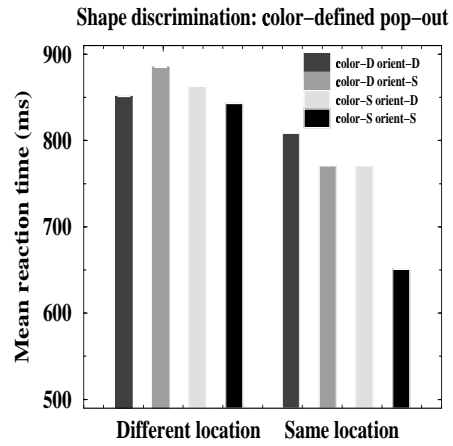
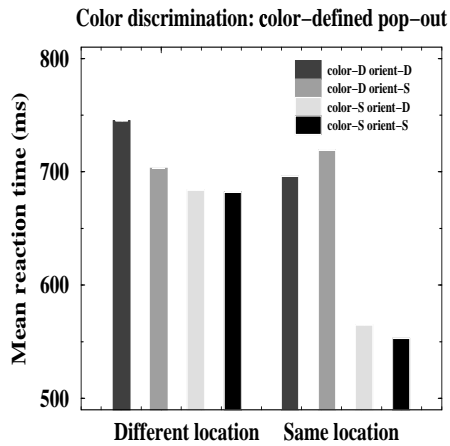
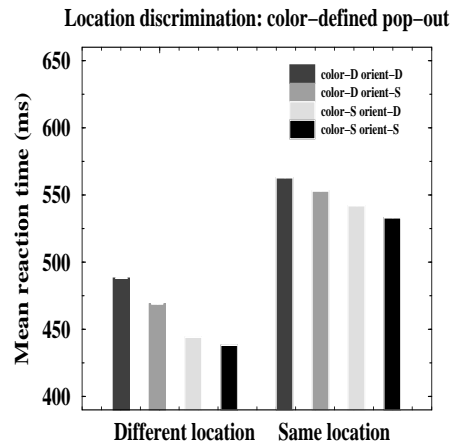
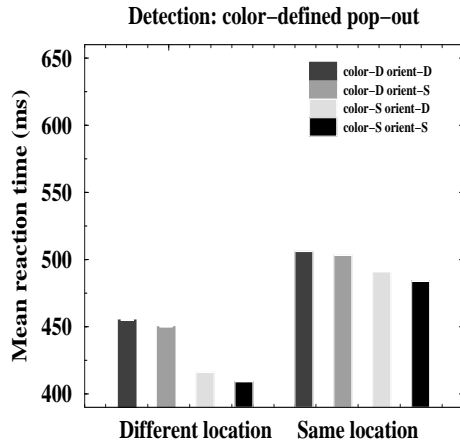


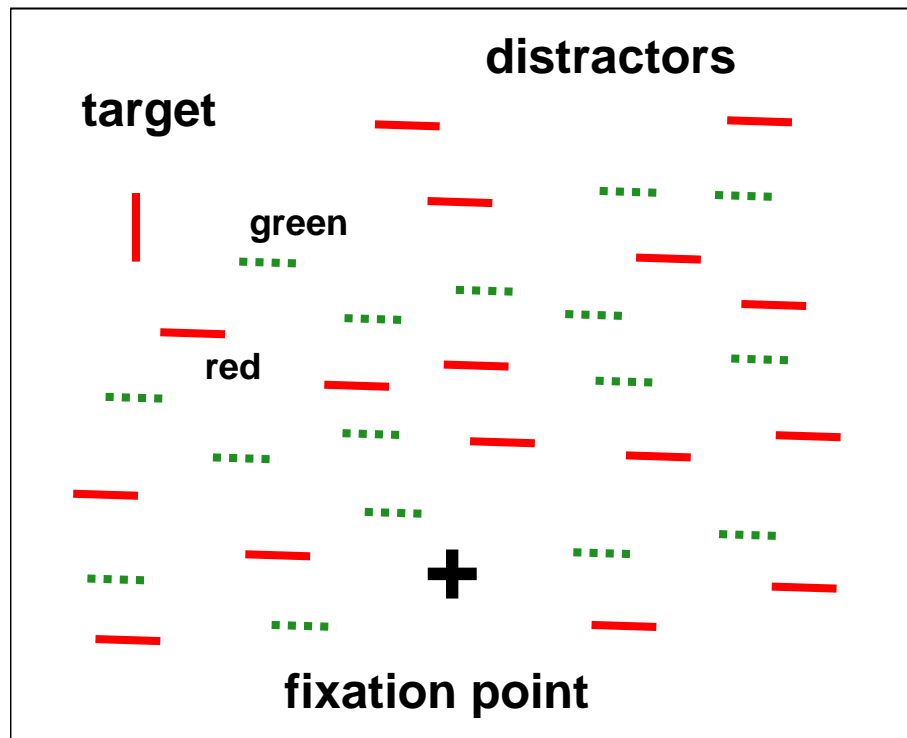
fixation point

### Display: color pop-out









### Display: orientation pop-out

