Temporal and spatial characteristics of attention to facilitate manual and eye movement responses.

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ABSTRACT

The speed of saccadic eye movements is enhanced when a temporal interval (gap) is introduced between the disappearance of a foveal fixation mark and the appearance of a peripheral target (the gap paradigm, Saslow, 1967; Fischer and Boch, 1983). Attention was shown to be involved in the gap paradigm (Fischer and Breitmeyer, 1987; Mackeben and Nakayama, 1993). Here, we investigated temporal and spatial characteristics of attention manipulating central fixation marks and peripheral targets. Results from three experiments indicated that (i) the speed of manual and eye movement detection was accelerated when a fixation mark changed abruptly (less than 100 ms) before its termination in the gap paradigm. (ii) The speed was further accelerated when a peripheral target location was pre-cued. (iii) Sufficient time for fixation (1000 ms) was necessary for the facilitation. These results suggest that fast and transient attention at the fixation spot facilitates attentional disengagement process (Posner et. al., 1984) that urges a spatial-orienting mechanism. Sustained attention (Nakayama and Mackeben, 1989) is required in the engagement process during the fixation.

INTRODUCTION

1. Attention and eye movements

The relationship between selective spatial attention and eye movements has been speculated over years. As early as 19th century, Helmholtz (1896) observed an advantage of spatially attended locus for recognizing letters in the peripheral visual field without a shift of gaze. This observation suggested the mechanism of spatial attention that can operate independently of eye movements. However, it is only recently until truly objective research of attention was embarked (Eriksen and Hoffman, 1972; Posner, 1980; Bashinski and Bakarach, 1980; Remington, 1980) . Posner and his colleagues (Posner, 1974, 1978; Posner, Snyder, and Davidson, 1980) devised a visual cueing paradigm to investigate a spatial aspect of attention. A visual cue was presented at one side of the peripheral visual field, followed by a target presented at the same or the opposite side. Spatial attention was studied by assessing the relationship between cue and target locations. Fixation was maintained at the central spot, attempting to dissociate attention from eye movements. Using this paradigm, Posner (1980) discovered a component of attention independent of eye movements. A speed of detection, measured by reaction time (RT), was facilitated at the pre-cued ('valid') side of the visual field, as compared to the opposite ('invalid') side, even though eyes are fixated at the central spot. The allocation of attention in the absence of such eye movements was referred as *covert orienting*, and distinguished from *overt orienting* that involves oculomotor responses such as saccadic eye movements. In order to explain a dynamic aspect of attention, Posner et. al. (1984) proposed a three-step processing model of movement (shift) of attention: attentional engagement, disengagement, and re-engagement. According to their claim, attention is first attracted to one spatial location where visual stimulus is presented (engagement). Second, it ought to be released to move toward other locations when the stimulus disappears (attentional disengagement). Finally, attention is *re*engaged to a novel visual stimulus appearing at a different location. The limited spatial range of focal attention, often described as a 'spotlight' metaphor, was found to move quite rapidly. At least 50-100 ms was necessary for attention to shift from a central fixation spot to a target at a distance of 8 degrees of visual angle (Sagi and Julesz, 1985), while 180-200 ms was found to be necessary for normal saccadic eye movements to be activated (Fischer and Ramsberber, 1984).

2. Express saccades

In the literature of saccades, there were occasional findings of the shortening of saccadic latency. Saccadic responses are facilitated when a temporal gap or interval is introduced between fixation offset (disappearance) and target onset (appearance) (Saslow, 1967). Using this paradigm, Fisher and his colligues found extremely rapid eye movements with latencies of 80-120 ms, which are referred as 'express' saccades (Fischer and Boch, 1983; Fischer and Ramsperger, 1984). To explain this phenomenon, Fischer and Breitmeyer (1987) applied the attention disengagement hypothesis. First, attention is assumed to be engaged at the fixation spot. Then, it is disengaged when the fixation mark disappeared. When a visual target appears, attention shifts to a target location and re-engages to the new target. This attentional shift urges rapid saccadic eye movements. Mackeben and Nakayama (1993) explicitly tested this hypothesis in examining a time course of vernier discrimination performance. Using a spatial cueing paradigm combined with backward masking (Bergen and Julesz, 1983; Sagi and Julesz, 1984), they found that attention shifted very rapidly within 100 ms from the fixation removal without eye movements in the gap condition, yielding improved vernier discrimination performance at a cued location. The development of this improvement was much slow when fixation is not terminated ('overlap' condition). The fast time course of facilitation overlaps that of express saccades. Maximal facilitation was observed with gap duration 200 ms (Mayfrank et al., 1986), suggesting that attention and express saccades are highly correlated. Several other studies have been conducted that attempted to dissociate the locus of visual attention from that of visual fixation (Kingstone and Klein, 1993: Tam and Stelmach, 1993). These experiments showed that removing the central fixation stimulus resulted in shorter latencies whether the central fixation stimulus was attended or not.

3. properties of attention

Although now it becomes evident that attention can be involved in generation of express saccades, the developmental process of attention before eye movements is still unclear. In the present study, we have investigated temporal and spatial properties of attention, namely its disengagement processes during the course of fixation changes. As noted, attentional disengagement is very rapid, completing within 50-100 ms after the fixation offset (Mackeben and Nakayama, 1993). The time course of this rapid process coincides that of a transient component of attention that develops within 100 ms (Sagi and Julesz, 1985;

Nakayama and Mackeben, 1989, Hikosaka et. al, 1993a) . This component operates involuntary, compulsory, and in a stimulus-driven manner, suggesting an involvement of the early visual processing (Sagi and Julesz, 1985; Nakayama and Mackeben, 1989; Hikosaka et. al., 1993a). Here, we assume that the transient component of attention and the disengagement process is tightly linked. Then, one possible scenario would be that the transient component urges or reinforces the disengagement process to be activated more vigorously and induces rapid shifts of attention. Experiment 1 was designed to test this hypothesis whereby the transient component of attention was manipulated at a locus of fixation. The abstract form of the results were presented elsewhere (Shimojo and Tanaka, 1994).

EXPERIMENT1: *Transient signals facilitate attentional disengagements*

In the first set of experiments, we tested whether a transient signal change at the fixation spot before its offset facilitates the attention disengagement process and accelerate responses. An abrupt signal (duration 50 ms) was given to the fixation mark before its termination. Different dimensions of visual features such as luminance, color, and orientation were used for the abrupt change. Three sub-experiments were designed accordingly for the change, which will be referred as **the luminance experiment**, **the color experiment**, and **the shape experiment**, respectively. We expected a similar facilitation across different dimensions assuming that abrupt signals attract attention in a involuntary and stimulus-driven manner (Remington et al., 1992; Muller and Rabbitt, 1989). Both manual responses using button press (without eye movements) and saccadic eye movements were tested.

Methods

Stimuli

Stimuli were consisted of a fixation cross extending 0.2° × 0.2° of visual angle, and a target square extending 0.6° × 0.6°. The distance between the fixation and the target stimuli was 11.0°, and the distance between left and right target stimuli was 19.3°. The luminance of the target was 2.58 cd/m^2 with the background luminance 0.01 cd/m^2. In the luminance experiment, the fixation cross was either in gray (referred as **'dim'**, 0.34 cd/m^2), or flashed (referred as **'bright'**, 8.13 cd/m^2). In the color experiment, the fixation was a square extending 0.5° × 0.5°, and its color was either red [$0.53 cd/m^2$, hue (0.33, 0.56)] or green [$0.22 cd/m^2$, hue (0.62, 0.26)]. The luminance of red and green in this and the following experiments were adjusted as close to equiluminant as possible by *Minimum Flicker Method* (Wagner and Boynton, 1972). In the orientation experiment, the fixation was a gray ($0.34 cd/m^2$) rectangle extending $0.15° \times 0.50°$, elongated either in a vertical or horizontal manner. Stimuli were presented on a cathode ray tube (CRT) display (Commodore 1840S, non-interlaced; frame frequency=60Hz). Stimulus presentation, timing control, and data acquisition were employed by a microcomputer (Amiga 1200; Commodore) using the Amiga disc operating system.

Experimental procedures

In the luminance experiment, there were two major conditions; the 'overlap' condition where the fixation stimuli was kept on, or the 'gap' condition where the fixation stimuli was extinguished. These conditions were extended by adding an abrupt signal change to the fixation mark (duration 50 ms), producing the following conditions: (1) **Dim overlap**, (2) **Dim-Bright-Dim overlap**, (3) **Dim gap** and (4) **Dim-Bright gap (see Figure 1)**. Similarly, four conditions were conducted in the color experiment: (1) **Green overlap**, (2) **Green-Red-Green overlap**, (3) **Green gap** and (4) **Green-Red gap**. In the orientation experiment, they were (1) **Vertical overlap**, (2) **Vertical-Horizontal-Vertical overlap**, (3) **Vertical gap** and (4) **Vertical-Horizontal gap**. A trial started with an inter-trial interval with duration of 500 ms. In the luminance, color or orientation experiment, either a dim, green or vertical fixation stimulus was presented in the center of the screen for the duration of 850 or 1450 ms (randomly chosen). The duration is referred as inter-stimulus-interval (ISI). The fixation stimulus turned either bright, red or horizontal for 50 ms in conditions 2 and 4 ($=fixation$ *change*), or remained dim, green or vertical in conditions 1 and 3 ($=fixation$ *unchanged*). This duration was determined considering the time course of a transient component of attention (Nakayama and Mackeben, 1989). For the next period referred as **gap duration** which is randomly chosen from 50, 250 or 450 ms, the fixation stimulus became either dim, green or vertical again (conditions 1 and 2), or extinguished (conditions 3 and 4). The four conditions were counterbalanced. Note that the condition 2 was set especially to examine timing or warning effects caused by the transient signal change (Ross and Ross, 1981; Reuter-Lorenz et al., 1991; Juttner and Wolf, 1992). If transient changes serve only as a warning or alartness signal, then responses both in gap and in overlap conditions should be equally facilitated. The target was presented at the top-left or the top-right of the fixation mark (randomly chosen) and remained until detected. Subjects were seated at the distance of 57cm from the display, and asked to maintain the fixation and detect the peripheral target as fast as possible (simple detection task). Reaction time (RT), measured by a button press, was defined as the time between the onset of target and the onset of response. Catch trials, where no target was presented, were employed in 20% of the trials (counterbalanced) to assure subjects to respond to the target appearance, but not to the transient fixation change (Juttner and Wolf, 1992). There were four types of catch trials in the luminance experiment: (1) Dim-overlap catch, (2) Dim-Bright-Dim catch, (3) Dim-gap catch and (4) Dim-Bright-gap catch. Similar catch trials were employed in color and orientation experiments. Feedback was given to catch trials when subject pressed the button too fast (RT<700 ms). The viewing condition was binocular and the head was stabilized by a chin rest. Eye fixation was monitored in selected sessions by Ober 2 eye-movement detection system (Permobil Corp., Timra, Sweden). The temporal resolution was 120Hz. The spatial resolution was measured and the minimum accuracy was found to be 18 minutes of arc. The subject experienced dark adaptation for two minutes before the experiment. A practice session (100 trials) was employed in the initial session.

Subjects

Four observers participated in each sub-experiment in this and following experiments, unless mentioned otherwise. The observers, except Y.T. and S.S. (authors), were the students of Massachusetts Institute of Technology (age: 22-27), who did not know the purpose of the experiments. The authors were highly experienced to the paradigm described here. All subjects had normal or corrected-to-normal visual acuity and normal color vision.

Data analysis

In each sub-experiment, data were analyzed with respect to four conditions, three gap duration periods, and two target locations, each repeated twenty times, consisting of the total number of trials 480 ($4 \times 3 \times 2 \times 20$) for each subject. RTs below 100 ms and above 1300 ms were eliminated from the analysis. In the saccadic-eye movement task, an accepted range was 50-1300 ms. Sessions where a false alarm rate (percentile of erroneous responses in the catch trials) exceeded 10% were eliminated. The data from each subject were combined for a three-way repeated measures analysis of variance (ANOVA; *Condition* × *Gap duration* × *Location*) in each sub-experiment.

Results

In *the luminance experiment*, no sessions were excluded because all subjects exceeded 90% of correct performances. Averaged correct response was 96%. The differences of false alarm rates in the catch trials were negligible (see Table 1). This trend was common to all experiments employed (Table 1) and will not be mentioned later. Eye fixation was monitored during the selected session, and found to be maintained within a limited range of space (less than 30 minutes of arc from the central fixation cross). Repeated measures analysis of variance (ANOVA) shows the significant main effects of Condition, Gap interval, and their interaction (see Table 2). Because no difference was found between two locations [$F(1, 24) < 1$], data were pooled in terms of location. The tendency was identical among luminance, color, and orientation experiments. RTs averaged across four observers were plotted as a function of gap duration (see Figure 2a). As is clearly seen, two gap tasks (Dim gap and Dim-Bright gap) produced shorter RTs at all gap durations compared with two overlap tasks (Dim overlap and Dim-bright overlap). The shortest responses were found at the gap duration 250 ms. This is a typical gap effect found in the literature. Within the gap condition, the Dim-Bright-gap condition produced shorter RTs (mean±SE, $57 \pm 18ms$, $p<0.01$) compared with those in the Dim-gap condition. On the other hand, no difference was found between the Dim-overlap and the Dim-Bright-overlap conditions ($17 \pm 45ms$, $p>0.05$). The tendency was similar in the *color experiment* and the *orientation experiment*. Clear gap effects were found in both the Green-gap and Green-Red-gap conditions (see Figure 2b) as well as the Vertical-gap and Vertical-Horizontal-gap conditions (five subjects, Figure 2c). RTs were shortest in the Green-Red-gap and Vertical-Horizontal-gap conditions, respectively. The shortest RTs were found at the gap duration 250 ms in both experiments with gap tasks which contained transient fixation changes. To evaluate the magnitude of the gap effect, a saving in RTs in the gap condition against the overlap condition was calculated and plotted at each gap duration (Figure 2d). Transient signals at the fixation (luminance, color and orientation) produced more savings in RTs than without transient signals. The average saving in RTs with transient signals in the luminance experiment (referred as ‘Dim-Bright’ in the graph) was $137 \pm 33ms$, compared with $66 \pm 29ms$ without transient signals ('Dim'). Similar tendencies were found both in color and orientation experiments . RT savings were $120 \pm 42ms$ versus $57 \pm 31ms$ in the color experiment, and $115 \pm 21ms$ versus $63 \pm 32ms$ in the orientation experiment, respectively. Note that the peak in saving was observed in the gap duration 250 ms with or without transient signals, suggesting an involvement of common process to both gap tasks. We also evaluated the effects of the transient signal change within gap tasks and overlap tasks, respectively (Figure 2e). Saving in RTs, by calculating the difference of RT between the Dim-gap and the Dim-Bright-gap conditions for example, was plotted at each gap duration (Figure 2e). Similar calculation was employed in overlap conditions as well. Only gap tasks showed the significant saving in RTs ($55 \pm 15ms$, $67 \pm 19ms$ and $45 \pm 13ms$, in the luminance, color and orientation experiments, respectively, all $p0.01$, two-tailed t-test), whereas no saving was found in the overlap tasks ($-11 \pm 15ms$, $-16 \pm 25ms$, $-13 \pm 10ms$, all p 0.05, two-tailed t-test). Significant advantage was observed at gap duration 250 ms in some of the overlap tasks (both color and orientation experiments), compared with other gap durations. This might be due to a learning effect of a specific timing sequence(Fischer and Ramsperger, 1986), because it was most evident with the experienced observer Y.T (data not shown).

Saccadic eye movements

To compare eye movements with manual responses, the reaction time of saccadic eye movements were measured. Subjects were instructed to foveate a peripheral target as fast and accurately as possible. Saccadic reaction time (SRT) was defined as the time from the target onset to the initiation of the saccadic eye movement. Eye blinks were selected inspecting the raw data and taken out from the analysis. Results indicate a clear gap effect. SRTs were shorter in both of the gap conditions compared with those of the overlap conditions, with the 'dip' at the gap duration 250 ms (Figure 3a). We consider this as a modified form of *express saccades* (Fischer and Boch, 1983; Fischer and Ramsperger, 1984) because of the following two reasons. (1) The SRTs are relatively shorter (150-170 ms) compared with overlap conditions. (2) The shorter RTs were observed only at the limited gap duration (250 ms), consistent with the literature. Note that the range of the latencies were slower than the original express saccades (Fisher and Boch 1983, 100-140 ms). This is possibly due to (1) the different distance tested (11.0° versus 4.0°), (2) the introduction of temporal uncertainty by randomizing intervals and (3) the introduction of spatial uncertainty by randomizing target locations. In the Dim-Bright-gap condition, SRTs were even shorter than those in the Dim-gap condition with a magnitude of $40 \pm 12ms$, consistent with manual responses described above. The magnitude of SRTs for some subjects (100-120 ms, M.M. and Y.T.) was as short as the original express saccades (Fisher and Boch, 1983, 100-140 ms), albeit larger target distances (11.0 deg.). The same two subjects showed a RT reduction at gap duration 250 ms ($p < 0.01$) in the Dim-Bright-Dim overlap condition, probably due to the learning effect similar to the color and orientation experiments. The magnitude of RTs of one subject (S.S.) was relatively long (280-450 ms). This might be attributed to tiredness from the midnight (1:00am) session or to his age (39 years old), although overall pattern of results was similar to other subjects.

Discussion

The results of this experiment demonstrated the following aspects. (1) An addition of a transient component at the fixation spot facilitated both manual and eye movement responses. (2) This facilitation was evident only when the fixation was removed (gap condition). (3) Different dimensions of visual feature (luminance, color, or orientation) of the transient change did not affect the facilitation. Here, we compared saccadic eye movements and manual responses using highly compatible stimuli. Similar pattern of results, facilitation in the gap task and its further enhancement with transient fixation signals were observed. This suggests an involvement of a common functional mechanism. One may speculate that transient alternation of fixation marks served as a general timing cue or a warning signal (Reuter-Lorenz et al., 1991; Ross and Ross, 1981; Juttner and Wolf, 1992; Posner and Boies, 1971; Tanaka and Sagi, 2000). To address this question, RTs were compared between gap and overlap conditions when both contained transient changes. Considering that additional transient signals produced the RT reduction (saving) in the gap condition whereas no reduction was found in the overlap condition, it seems unlikely that only timing or warning signals were responsible for the facilitation (Reuter-Lorenz et al., 1991; Ross and Ross, 1981). However, there was a common tendency that RTs were shorter with gap duration 250 ms in conditions 2, 3 and 4 where timing cues were equally given to the fixation mark. We attributed it to the learning effect of the specific timing, however it was not clear how attention is involved to this specific timing sequence. To test the involvement of attention more directly, we evaluated **spatial attention** in the next experiment. Attention has been regarded as showing 'spot-light' type of characteristics; i.e., reduction of RTs in detection, and reduction of thresholds in discrimination was observed when a location is pre-cued, where attention is properly directed(Posner, 1980; Bashinski and Bacharach, 1980). We used this paradigm in experiment 2. Attention was driven by a peripheral visual stimulus (cue) in an automatical, compulsory and stimulus-driven manner (endogenous covert attention). If timing/warning signals are critical, thus the abrupt changes are irrelevant to location, then the RT reduction would be homogeneous across locations. In contrast, if the abrupt changes at the fixation spot are critical to spatial attention, then RTs would be different at different locations.

EXPERIMENT 2: *Spatial attention*

In this experiment, the involvement of attention to the fixation stimulus was tested manipulating spatial factors(Posner, 1980; Tam and Stelmach, 1993; Kingstone and Klein, 1993). The first set of experiment, referred as **the peripheral cueing experiment**, was employed to directly assess the involvement of attention using the cost-benefit paradigm (Posner, 1980; Kingstone and Klein, 1993; Nakayama and Mackeben, 1989). In this paradigm, spatial selective attention can be quantified by a 'benefit' (i.e., saving of RT) at a pre-cued location, accompanied with a 'cost' (increase of RT) at non-cued locations. We assumed that spatial attention was involved during the transient fixation change and its termination. Then, the facilitation ('benefit') should be specific to the pre-cued location in the Dim-Bright-gap condition rather than in the Dim-Bright-overlap condition. In contrast, if there was no 'benefit' at the pre-cued location in the Dim-Bright-gap condition, that would argue for the warning/timing hypothesis where 'benefit' is general and independent of location. The second set of experiment referred as **the whole flash experiment** was employed to determine whether the facilitation using additional signals was stemmed from local transient components (fixation change) or global timing signals independent of location (Mackeben and Nakayama, 1993). Assuming that spatial selective attention operating an 'exogenous' orienting mechanism is involved, we expected that the local fixation change was responsible for the facilitation, producing the reduction in RTs.

Procedures

In the *peripheral cueing experiment*, conditions similar to experiment 1 in terms of fixation manipulation (Dim/Bright × overlap/gap) were tested (see Figure 4). The time course of one trial was as follows: after 500 ms of blank period (inter-trial interval) a dim fixation mark appeared for either 850 or 1450 ms (randomly chosen). Then, the fixation mark flashed for 50 ms (**bright** fixation) in conditions 2 and 4, whereas it remained 'dim' in conditions 1 and 3. Immediately after that, a cue was presented briefly (17 ms) at a possible target location (top-left or top-right, randomly chosen) at a distance of 11.0° from the fixation mark with the dim fixation cross (overlap, conditions 1 and 2) or without it (gap, conditions 3 and 4). The cue disappeared and only blank field with (conditions 1 and 2) or without (3 and 4) the fixation followed for 100 or 200 ms (randomly chosen). This period is referred as *cue lead time* or **CLT**). This duration was determined considering both gap durations of express saccades (maximal around 150-200 ms, Fisher and Boch, 1984) and time course of covert attentional shifts (maximal with cue-lead-time of 100 ms, Posner and Cohen, 1984). The peripheral cue was a cross, the same shape, size, and luminance as the fixation stimulus. After the CLT, a target was presented at the same or the different side from the cue. The location relationship between cue and target was counterbalanced between left-left, left-right, right-left and right-right. The left-left, or right-right situations were referred as *valid*, while the left-right and right-left situations were referred as *invalid* (Posner, 1980). To minimize possible forward masking effects, we used a grey line-drawn square as the target (size: $2^\circ \times 2^\circ$) with an inner area blanked. The cue (cross: $0.2^\circ \times 0.2^\circ$) appeared in the well center of the square, thus there was no spatial overlap between cue and target. To minimize effects of eye movements as well as possible masking effects, both cue and target durations were set as short as 17 ms. Catch trials were employed in each condition in both experiments (see experiment 1). In the *peripheral cueing experiment*, data were analyzed with respect to the 4 conditions (including 20% of catch trials), 2 CLTs, 2 locations, and 2 cue-target relationships ('valid/invalid', termed $Validity$). Each cell was repeated 12 times, thus the total trial number was 384 ($4 \times 2 \times 2 \times 2 \times 12$). Data were combined across subjects and a four-way repeated ANOVA ($Conditions \times CLT \times Location \times Validity$) was conducted. Other procedures were the same as experiment 1.

In the *whole flash experiment*, an entire field of display that extends 19° × 27° of visual angle was manipulated. The original color of the screen was green [hue: (0.33, 0.56), luminance: 0.53cd/m^2]. This turned red [hue: (0.62, 0.26), luminance: 0.22cd/m^2, equiluminant] for 50 ms, and turned green again during the gap duration. The luminance of the target was set at 8.13 cd/m^2, higher than that in experiment 1 to compensate a possible forward masking effect from the red background. The following four conditions were compared: (1) **Dim-background Red**(termed *bkgRed*)**-Dim overlap**, (2) **Dim-Bright-Dim overlap**, (3) **Dim-bkgRed gap**, and (4) **Dim-Bright gap**. A comparison between conditions 3 and 4 allowed us to test whether the RT reduction was specific to the locus of fixation or whether it was based on general timing/warning effects independent of location, because this experiment contained the same timing cues in all conditions and the only difference was a spatial aspect of the transient changes. Therefore, if the timing/warning signal is the main factor, all conditions should lead to identical results. On the contrary, if spatial attention is involved, results should differ between conditions. Four subjects participated in each sub-experiments.

Results

In *the peripheral cueing experiment* the rate of the correct response was 97% in the catch trial. The analysis of variance (ANOVA) showed no differences in CLT (between 100 and 200 ms, $p < 0.25$) nor in *Location* ($p < 0.34$), thus data were pooled in terms of CLT and *Location* (Table 3). In both of the Dim gap and Dim-Bright gap conditions, RTs were significantly shorter in 'valid' than 'invalid' conditions ($p<0.001$ and $p<0.0001$ respectively, see Figure 5a), whereas there was no statistical difference between 'valid' and 'invalid' locations in both of the Dim-overlap ($p > 0.10$) and Dim-Bright-overlap ($p > 0.05$) conditions. This indicates substantial 'benefit' in the gap conditions, whereas little 'benefit' in the overlap conditions (see Figure 5b). Note that RTs were shortest at the 'valid' location in the Dim-Bright-gap condition, suggesting that attention shifts were enhanced at best in this condition. RTs in the Dim-Bright-gap condition were shorter than those in the Dim-gap condition ($p < 0.001$), whereas RTs in the the Dim-Bright-Dim-overlap condition were identical to the Dim-overlap condition ($p < 0.12$), suggesting that the transient component at the fixation spot produced the further RT reduction due to the 'valid' pre-cue in the gap task.

In *the whole flash experiment*, the correct response rate was 95% in the catch trial. Mean RTs were shorter in the Dim-Bright-gap condition ($p < 0.001$, Figure 6) compared with the Dim-bkgRed-gap condition. This is against the general warning hypothesis, and argues for the spatial attention hypothesis. The difference was rather small for two subjects (Y.T. and S.M.) where overall RTs were generally small (463 ms and 324 ms respectively, compared with 551 ms for S.S. and 523 ms for J.A.), suggesting that timing of the background flash was learned. RTs in two overlap conditions (Dim-Bright-Dim overlap and in the Dim-bkgRed-Dim overlap) were very similar, longer than those of the two gap conditions, again inconsistent with the general warning account: according to the hypothesis, the identical time course across all conditions should have resulted in identical RTs, which was not the case. Generally, RTs were long at the gap duration 50 ms, reflecting possible forward masking effects from the fixation or the background change (stimulus onset asynchrony, 50+50=100 ms). This is consistent with visual masking effects in the literature (Breitmeyer and Ganz, 1976).

Discussion

In the whole flash experiment, both overlap conditions (conditions 1 and 2) yielded significantly longer RTs than those of the gap conditions (conditions 3 and 4). This rules out the general timing/warning hypothesis (Reuter-Lorenz et al, 1991, Ross and Ross, 1981). Even though the time courses were identical, the RT reduction occurred specifically in the gap task with the local fixation change, but not with the global visual field change. This suggests that timing signals independent of location are not critical for the RT reduction. Instead, transient signals at a particular location (=fixation spot) are critical to the effect. Results in the peripheral cueing experiment showed the 'benefit' for the cue towards target at the 'valid' location, indicating the direct evidence of the involvement of spatial attention to the RT reduction (Posner, 1980; Posner and Cohen, 1984; Mackeben and Nakayama, 1993). The difference between the large 'benefit' in the gap conditions and the little 'benefit' in the overlap conditions is not compatible with the warning/timing hypothesis, because as we noted, this hypothesis predicted non-selective 'benefit' for both gap and overlap conditions. Results indicate, on the contrary, a significant 'benefit' in the gap conditions but much less 'benefit' in the overlap conditions. Furthermore, the 'benefit' was particularly enhanced with additional transient signals to the fixation/attention locus, suggesting again the involvement of attention. Another indirect evidence that rules out the timing/warning hypothesis was no statistical difference (11±12 ms) between the Dim overlap and the Dim-Bright-Dim overlap conditions. If the timing/warning hypothesis holds, the difference of these two overlap conditions should be as much as that of the

Dim-gap and the Dim-Bright-gap conditions (34±10 ms), which was not the case. This is consistent with the results of experiment 1.

EXPERIMENT 3: *Temporal attention*

In the previous experiment, attention was assessed in space. In this experiment, the temporal aspect of attention was addressed. In the first set of experiment referred as **the gap experiment**, the duration of the transient fixation change was manipulated to find an optimal duration of the visual transient. In the second set of experiment referred as **the initial fixation experiment**, the duration of the initial 'dim' fixation stimulus was chosen based on either a transient (100 ms) or a sustained component (1,000 ms) of attention (Nakayama and Mackeben, 1989; Hikosaka et al., 1993a). Attentional engagement/disengagement model predicts that spatial attention remains at the locus of fixation in the overlap condition, while it moves swiftly to a peripheral target position in the gap condition (Posner et al., 1984; Fischer and Breitmeyer, 1987). In other words, attention, which is first *engaged* at the locus of fixation, is "released" with its termination (*disengagement processes*). Our hypothesis is that initial engagement processes need time, requiring sustained attention (Nakayama and Mackeben, 1989; Mayfrank et al., 1986). Therefore, we expect that an involvement of the sustained component (1,000 ms) during the initial fixation is necessary for the rapid disengagement process triggered by the transient fixation change and its removal. These two components would cause the maximal facilitation, producing fast responses.

Procedures

In the *gap experiment*, the the stimulus configuration was identical to the condition 4 (**Dim-Bright gap**) in experiment 1. The time course was identical except that the duration of the bright fixation was randomly chosen from either 17, 50, 100, or 400 ms on each trial, instead of the fixed duration of 50 ms. The gap duration (50/250/450 ms), the dim duration (850/1450 ms) and the target location (left/right sides) were all randomized. Catch trials were employed in 20% of trials. In the *initial fixation experiment*, only two conditions were randomly mixed on each trial: (1) **Dim-Bright-Dim overlap** and (2) **Dim-Bright gap**. The difference from experiment 1 was the duration of the initial (dim) fixation period. It was randomly chosen from either 100 or 1000 ms on each trial, instead of 850 or 1450 ms. We expected that the 1000 ms duration would activate the sustained component of attention and produce RT reduction. In the *gap experiment*, data were analyzed with respect to 4 bright durations, 3 gap duration periods, and 2 locations, with each repeated 12 times, composing 384 trials (4 × 2 × 2 × 2 × 12). In the *initial fixation experiment*, 2 conditions, 3 gap durations, 2 locations, and 2 dim durations (the duration of the initial fixation stimulus), with each repeated 12 times, composing 480 trials (2 × 3 × 2 × 2 × 20). Other procedures were identical to experiment 1.

Results

In both sub-experiments, the average false-alarm rate was 2% and 4%, respectively. In the *gap experiment*, ANOVA revealed no differences in RTs in *Location*, thus data were pooled. Significant factors from ANOVA analysis were shown in Table 3. The results in Figure 7a indicate the shortest RTs with the gap duration 250 ms in almost all *bright durations* (17, 50, 100 and 400 ms). RTs in the *bright duration* of 17 ms and 50 ms tended to be shorter for three subjects (Y.T., K.M., M.M.). These data demonstrate that there is an optimal gap duration around 250 ms from fixation termination, and this can be obtained with the *transient* (less than 100 ms) fixation change. In the *initial fixation experiment*, RTs were shorter in the gap conditions than in the overlap conditions ($p < 0.001$) with exception of subject N.M. (see Figure 7b). Furthermore, RTs were shorter with the dim duration 1000 ms (with the *sustained component*) compared with the dim duration 100 ms (with the *transient component*) in both gap ($p < 0.01$) and overlap ($p < 0.01$) conditions.

Discussion

The results of the gap experiment demonstrate an optimal temporal parameter for the RT reduction. The optimal gap duration was 250 ms, the time course roughly comparable with that for express saccades (200 ms, Fischer and Boch, 1984). The optimal duration of the fixation flash was less than 100 ms, confirming the hypothesis of the involvement of the transient component of attention to the abrupt attention shifts (Nakayama and Mackeben, 1989; Hikosaka et al., 1993a; Shulman et al., 1979). The results of the initial fixation experiment suggest that the sustained component before fixation termination is critical to the RT reduction, in accordance with the attentional engagement/disengagement hypothesis (Posner et al. 1984; Fischer and Breitmeyer, 1987; Mackeben and Nakayama, 1993). These results suggest an interaction process between transient and sustained attention that produces rapid disengagement and successive rapid attention shifts.

GENERAL DISCUSSION

We studied the characteristics of manual and saccade latencies manipulating spatial and temporal properties of the central fixation and peripheral visual stimuli. The results showed that a transient change at the fixation spot before its termination facilitated manual and saccadic responses to the peripheral targets in the gap paradigm.

1. Involvement of attention

The facilitation may have been attributed to the general warning or timing effects elicited by the fixation change (Reuter-Lorenz et al., 1991; Reuter-Lorenz et al., 1995; Ross and Ross, 1981). However, we think it unlikely because of the following reasons. (1) Responses were facilitated only when a target location was pre-cued, whereas genuine cueing of timing, using entire visual-field cues, did not help the facilitation to occur (Figure 6). (2) Responses were not facilitated in overlap conditions that contained the transient cues (i.e., the Dim-Bright-Dim overlap condition) although the time course was identical to 'transient' gap conditions such as the Dim-Bright gap condition (Figure 2). (3) In most of the experiments, the facilitation in the 'transient' gap condition was maximal at the gap duration 250 ms in both manual and eye movement tasks. This is inconsistent with the warning effects reported in the literature; the maximal effect was reported to occur with the gap duration 100-200 ms for saccades (Ross and Ross, 1981) and 300-500 ms for manual detection (Posner and Boies, 1971; Klein, 1980; Tanaka and Sagi, 2000). Instead, we consider an involvement of spatial attention as a possible mechanism for the explanation of results. The first reason for this argument is that the facilitation was linked with the spatial orienting mechanism. Pre-cued locations produced an enhanced facilitation in gap conditions, especially with transient signals (Experiment 2). The second reason is that the facilitation was associated with the visual stimuli (fixation mark) that contain a specific timing sequence (initial maintenance of fixation, its transient change and disappearance) at the specific location (fixation spot). This spatial-temporal specificity suggests a particular mechanism instead of general timing hypotheses. The third reason is common nature of performance (facilitation) between manual and eye movement responses in the gap task (Fischer and Rogal, 1986; Tam and Stelmach, 1993; Kingstone and Klein, 1993). One model to explain our results would be as follows. First, attention is engaged at the central fixation mark during the initial fixation period. Then, it is automatically or involuntarily released when the fixation mark is removed and oriented to the pre-cued locus. Transient attention facilitates the disengagement and successive spatial orienting processes. This model is consistent with the attention disengagement hypothesis (Meyflank et. al, 1986; Fischer and Breitmeyer, 1987; Brown and Breitmeyer, 1990; Mackeben and Nakayama, 1993). Our results emphasize the exogenous nature of facilitation elicited by central transient cues during the disengagement process. This was linked to the spatial orienting mechanism.

2. Interaction of two attention components

In order for the maximum facilitation to take place in our experiments, it was critical that the sustained component of attention was engaged at the fixation spot during the initial fixation period, followed by the transient component of attention to be activated at the same spot. This suggests an interaction between the sustained and transient component of attention (Nakayama and Mackeben, 1989). Here, we assume that the engagement process was tightly linked with slow and sustained attention (Hikosaka et al., 1993b). This might be associated with the fast and transient component of attention during the succesive disengagement process. This makes sense if we consider that the attentional engagement during the fixation may take time because of its voluntary and top-down nature (Fischer and Breitmeyer, 1987; Hikosaka et al., 1993b), whereas attentional disengagement requires reflexive, stimulus-driven and bottom-up operation (Nakayama and Mackeben, 1989; Mackeben and Nakayama, 1993; Hikosaka et al., 1993a). Indeed, studies of 'voluntary' saccades such as anti-saccade tasks show the modulation of sustained attention to the generation of eye movements (Fischer and Weber, 1996; Abrams et al., 1998), consistent with this account. The results of spatial pre-cue experiments indicate that the activities of transient attention is associated with the exogenous orienting system. If we assume that this exogenous operation is linked with the overt orienting process that initiates saccades, the hypothesis is compatible with the recent studies of Fischer, Weber, and their colleagues. Using a spatial (exogenous) cueing paradigm in the gap and overlap tasks (Cavan, 1996), they directly tested the involvement of spatial attention while employing the pro- and anti- saccade tasks whereby exogenous (bottom-up) or endogenous (top-down) attention was directed to the same or opposite side. They found that ‘transient’ (cue-lead time=100ms) anti-cues (shown to opposite to an attended side) facilitated generation of pro-saccades (eye movements to an attended side) (Fischer and Weber, 1998), whereas the significant number of error saccades were observed during anti-saccades with pro-cues (Weber et al., 1998). In both studies, frequencies of express saccades were increased when sustained (endogenous) attention was followed by a transient onset of peripheral cues, demonstrating an interaction between transient and sustained attention mechanisms in generation of express saccades. This is consistent with our interaction hypothesis. In the different line of studies, we found that a spatial orienting mechanism employing detection, location discrimination, or saccadic eye movement tasks (Posner and Cohen, 1984; Rafal et al, 1989) can be dissociated from a object recognition mechanism employing discrimination tasks of color, orientation, shape, etc (Tanaka and Shimojo, 1996). The orienting mechanism was found to be operated in a transient manner producing rapid attention shifts, whereas object recognition was found to be operated in a sustained and cumulative manner, generating visual short-term memory (Tanaka and Shimojo, 2000). Assuming that object recognition processes require active focal attention, these results are in accordance with the idea of distinction/interaction between a fast and transient orienting mechanism and a slow and sustained recognition mechanism, albeit the difference of the time course (300-1000 ms for the transient mechanism and 1-20s for the sustained mechanism, respectively). It is much less known, however, as to how those two systems interact.

3. Relation to other studies

Here, we review the relevant studies in the literature and discuss the relationship with our results. Tam and Stelmach (1993) examined the role of the ocular and attentional mechanisms in determining saccadic latencies by comparing manual responses and saccadic eye movements. They found that (1) turning off foveal or eccentric stimuli which were attended results in shorter saccadic latencies. (2) The saving of the latencies was greater with foveal than with eccentric attention. (3) Express saccades were more prominent with foveal offsets. These are consistent with our results of the attentional involvement. Kingstone and Klein (1993) measured saccadic latencies manipulating covert attention either endogenously and exogenously, by using central arrows or eccentric flash of dots, respectively, while maintaining or extinguishing the central fixation stimuli (dots or arrows). In comparing manual and saccadic responses, they found two components of facilitation; one which was attributed to the response preparation (warning) process and the other which was attributed to the oculomotor process induced by fixation offset (Munoz and Wurtz, 1993a,b). Our results of the facilitation with transient fixation change in the gap task (experiment 1) seems consistent with this model, although 'warning effects' by the transient signals in our study was found to be related to spatial attention (experiment 2). In the second experiment of Kingston and Klein (1993), saccadic facilitation in the gap condition was found compared with the overlap condition when the central fixation mark was brightened shortly (96 ms) before its termination. This is consistent with our results of eye movements (Experiment 1). Second, further (+19 ms) facilitation was shown with central brightening than peripheral brightening in the gap condition in the same experiment. This is consistent with our attention hypothesis, assuming that attention is stronger in the fovea than in the periphery (Tam and Stelmach, 1993). Cavan (1996) found the modulation of covert orienting to generate fast saccades using the spatial pre-cueing paradigm (Posner, 1980). An increased frequency of express saccades was found with an accompanied decrease in their latencies by valid peripheral cues. This is consistent with our results in experiment 2 that showed the involvement of the spatial orienting mechanism (see also Crawford and Muller, 1992). Recently, Kustov and Robinson (1996) found that the speed and direction of spatial orienting was modulated by microsimulation in the monkey superior colliculus (SC), demonstrating the direct link between attention and saccadic eye movements. This may be a possible neuronal mechanism common to attention and oculomotor programming, although other studies emphasize the role of parietal cortex during saccade tasks (Colby et al, 1996; Robinson et al, 1996)(Colby et al., 1996; Robinson et al., 1996). It is not clear whether some interaction between SC and the parietal cortex is critical in generation of saccades (Rizzolati et al, 1987; Rafal et.al, 1989; Fisher and Weber, 1993) .

4. Conclusion

In this study, we investigated temporal and spatial characteristics of attention. We found that the transient component of attention at the fixation spot before its termination facilitated manual and saccadic latencies of the peripheral target detection, possibly via attentional disengagement. The facilitation was tightly linked with the spatial orienting mechanism. In order for the maximal facilitation to occur, the sustained component of attention was necessary during the initial fixation period, suggesting the interaction between transient and sustained attention.

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FIGURE AND TABLE CAPTIONS

Figure 1

Schematized diagram of the luminance experiment (experiment 1). Four conditions were randomly mixed in a session: (1) Dim-overlap, (2) Dim-Bright-Dim-overlap, (3) Dim-gap and (4) Dim-Bright-gap conditions. Transient flash was given to the fixation cross in the conditions 2 and 4. Only one gap duration from 50, 250, or 450 ms was chosen on each trial. Target location (left or right) was randomized. Each condition contained 20% of catch trials where no target stimuli were presented.

Figure 2

Results of luminance, color, and orientation experiments in experiment 1. Data were combined across subjects. (a-c) Mean RTs were plotted for each sub-experiment against gap duration. Vertical bars in this and succeeding graphs indicate standard errors of mean. (d) RTs were re-calculated to demonstrate the gap effect. Savings in reaction time was plotted showing the difference between gap and overlap conditions. (e) RTs were re-calculated to demonstrate the effect of transient changes. Savings in reaction time was plotted showing the difference between with-transient and without-transient signals at the fixation mark.

Figure 3

Results of the saccadic eye movement task. Filled square indicates Dim-overlap, open square Dim-Bright-Dim- overlap, open triangle Dim-gap, and filled triangle Dim-Bright-gap conditions. Each subject shows a clear gap effect. Furthermore, latencies were further facilitated in the Dim-Bright-gap condition (see text in detail).

Figure 4

Schematized diagram of the peripheral cueing experiment (experiment 2). Similar conditions as experiment 1 were tested with additional transient peripheral cues (17 ms) at the top-left or top-right (randomized) of the fixation cross, followed by the interval (CLT). Target was presented at top-left and top-right (randomized), composing ‘valid’ (=identical cue-target location) and ‘invalid’ (=different) trials. Each condition contained 20% of catch trials where no target stimuli were presented.

Figure 5

(a) Results of the peripheral cueing experiment (experiment 2). The results of 4 subjects are combined and averaged. Dark bars indicate mean RTs for the ‘valid’ (same) location, and light bars indicate ‘invalid’ (different) location, for each condition. RTs at the same location significantly reduced in both gap conditions. (b) Cost-benefit analysis. The magnitude of ‘benefit’ (=saving in RTs) was much enhanced with 'gap' intervals, and maximal with transient changes of the fixation cross (Br-Gap) in the gap condition. Ovl=dim-overlap, Br-Ovl=dim-bright-dim-overlap Gap=dim-gap, Br-Gap=dim-bright-dim-gap conditions.

Figure 6

Result of the whole flash experiment (experiment 2). Filled square indicates Dim-BkgRed-Dim-overlap, open square Dim-Bright-Dim-overlap, open triangle Dim-BkgRed-gap, and filled triangle Dim-Bright-gap conditions. RTs were most reduced in the Dim-Bright-gap condition.

Figure 7

(a) Results of the gap experiment (experiment 3). Filled square indicates the bright duration 17 ms, open square 15 ms, open triangle 100 ms, and filled triangle 400 ms. Maxmum RT reduction occurred with the gap duration 250 ms. (b) Results of the initial fixation experiment (experiment 3). Filled square indicates the Dim-overlap condition with an initial dim duration=100 ms, open square that with 1000 ms, while open triangle indicates the Dim-gap condition with the initial dim-duration 100 ms, and filled triangle that with 1000 ms. RTs were shorter in the gap conditions than in the overlap conditions. Furthermore, RTs were further reduced when the initial dim fixation duration was long (1000 ms).

Table Captions

Table 2 *Note*. Data were analyzed with a three-way measures of analysis of variance for each sub-experiment. Only the main effects and interactions that were significant are given here. Cond.=Condition. * p<.05. ** p<.01.

Table 3 *Note*. Data were analyzed with a three-way measures of analysis of variance for each sub-experiment. Only the main effects and interactions that were significant are given here. * p<.05. ** p<.01.

Table 4 *Note*. Data were analyzed with a three-way measures of analysis of variance for each sub-experiment. Only the main effects and interactions that were significant are given here. * p<.05. ** p<.01.

Table 1: False alarm rates in catch trials

Experiment	ovl(%)	t$_ovl$(%)	gap(%)	t$_gap$(%)	overall(%)
Exp. 1					
luminance	4.1	4.2	3.8	3.9	4.0
color	5.5	4.6	5.7	4.9	5.0
orientation	5.0	3.6	3.7	5.3	4.5
eye movement	3.0	3.6	3.7	4.1	3.6
Exp. 2					
peripheral	2.6	2.9	3.1	3.4	3.0
whole flash	4.7	4.6	4.7	5.3	5.0
Exp. 3					
gap	2.2	2.1	1.7	2.0	2.0
initial fixation	4.5	3.5	3.7	4.3	4.0

Table 2: Summary of analyses of variance of experiment 1

Task-factor	F	p
Luminance experiment		
Condition	26.79	0.0001**
Gap duration	8.27	0.001**
Condition x Gap	2.17	0.05*
Color experiment		
Condition	15.44	0.0001**
Gap duration	14.16	0.0001**
Orientation experiment		
Condition	21.68	0.0001**
Gap duration	16.81	0.0001**
Condition x Gap	3.53	0.01**
Eye movements		
Condition	26.41	0.0001**

Table 3: Summary of analyses of variance of experiment 2

Task-factor	F	p
Peripheral experiment		
Condition	18.35	0.01**
Gap duration	8.25	0.01**
Whole flash experiment		
Condition	16.13	0.0001**
Gap duration	41.42	0.001**

Table 4: Summary of analyses of variance of experiment 3

Task-factor	F	p
Gap experiment		
Bright duration	9.73	0.001**
Gap duration	28.82	0.0001**
Location x Gap	4.04	0.01**
Initial fixation experiment		
Dim duration	10.7	0.0001**
Gap duration	14.6	0.0001**

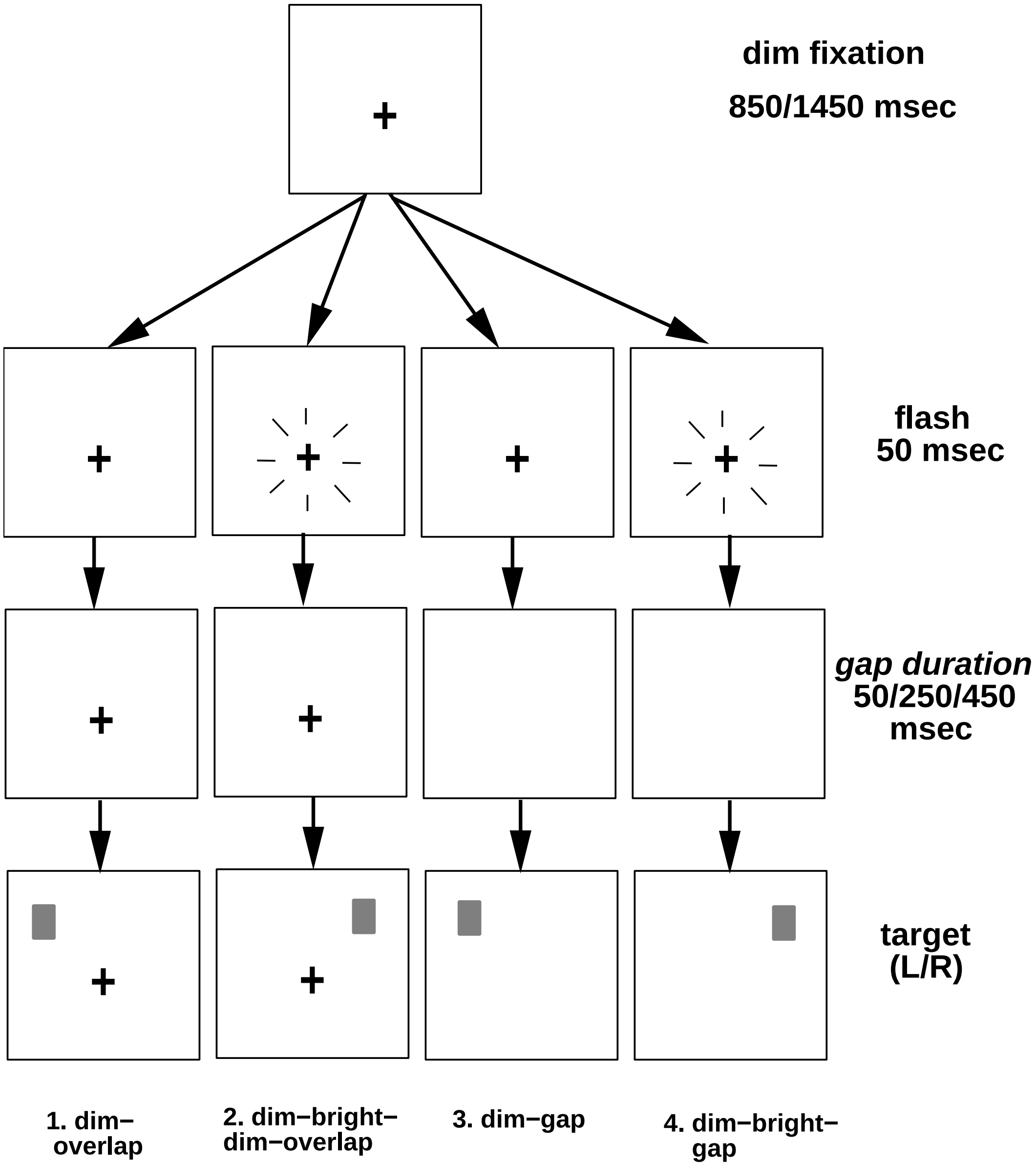


Fig. 1.

Tanaka & Shimojo

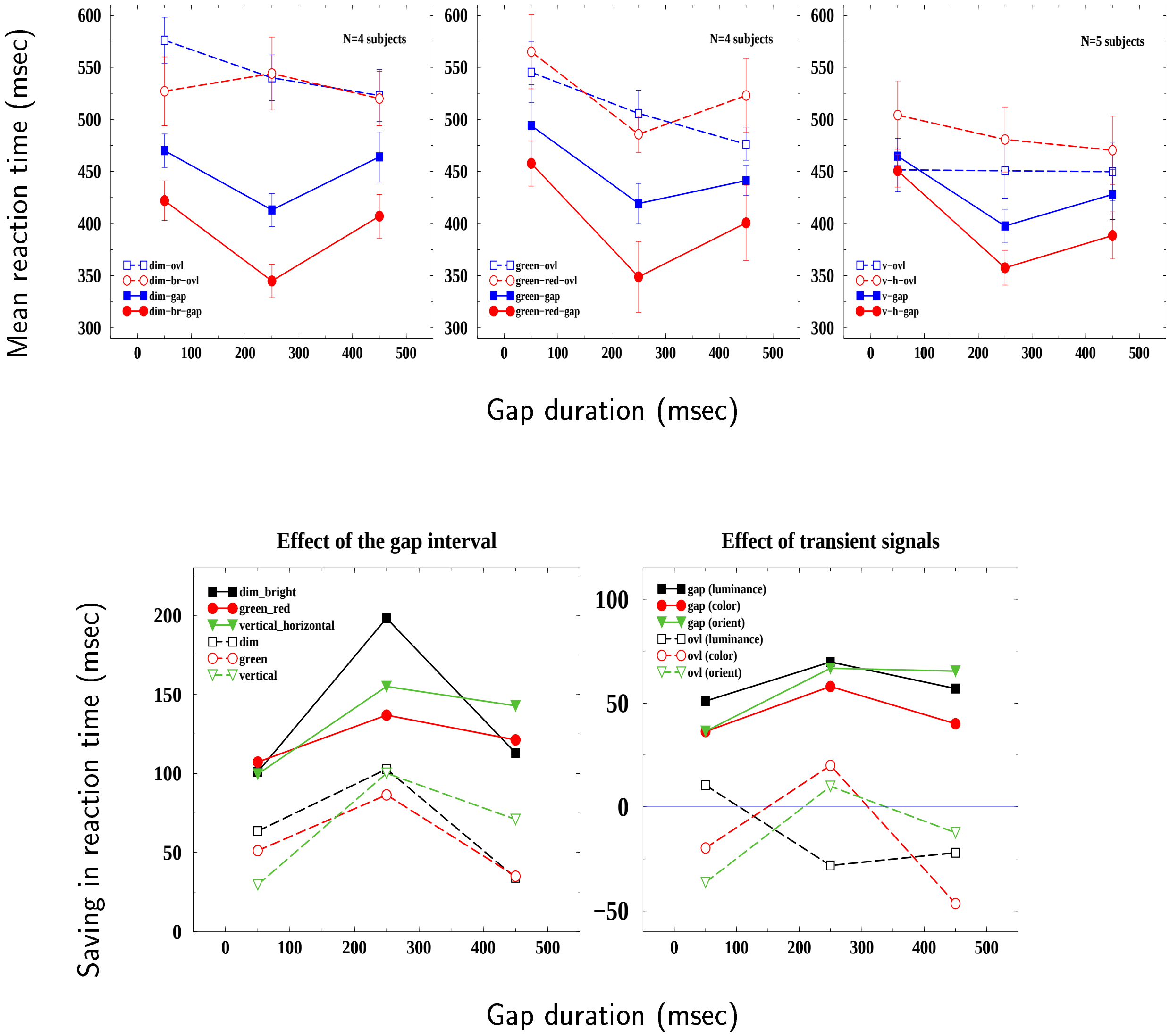


Fig. 2.
Tanaka & Shimojo

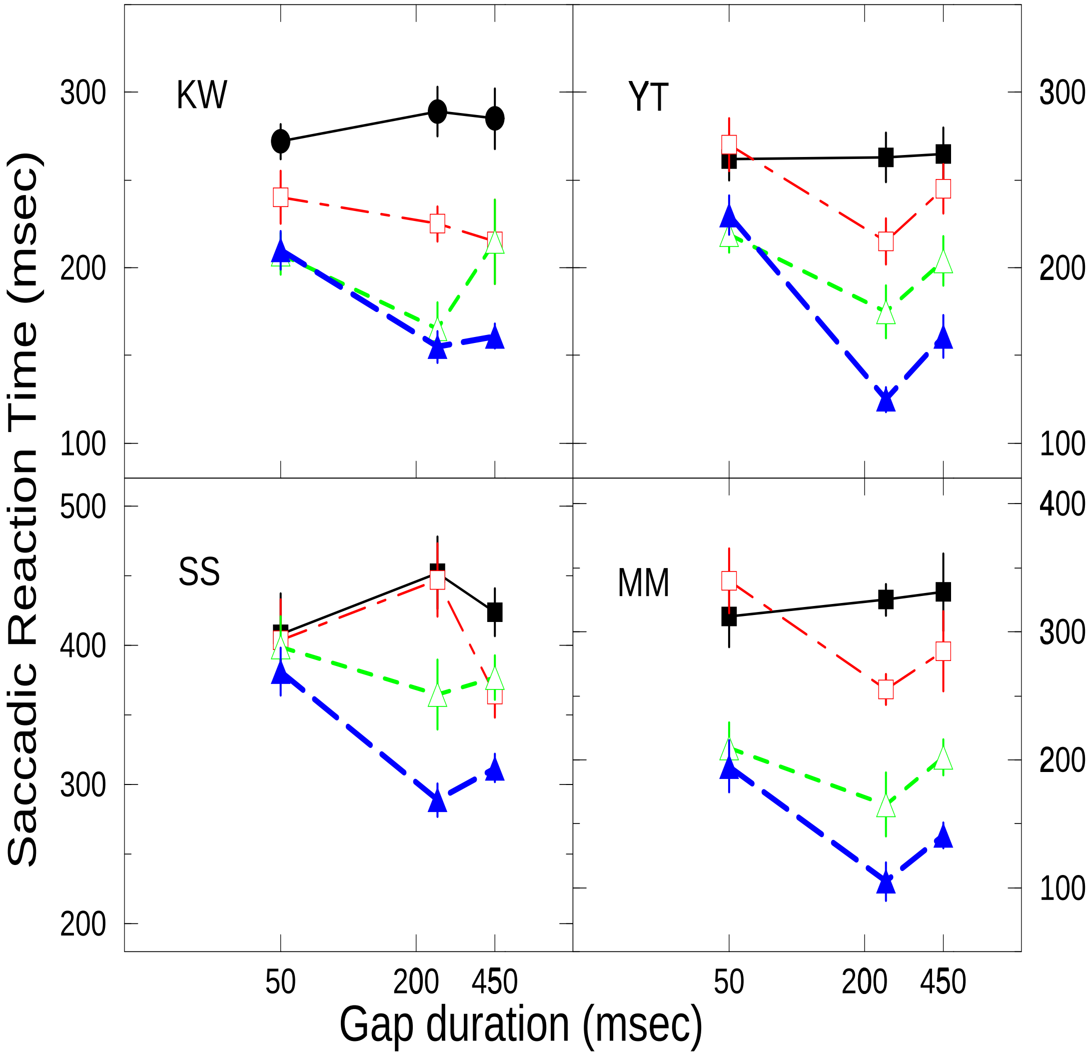


Fig. 3.

Tanaka & Shimojo

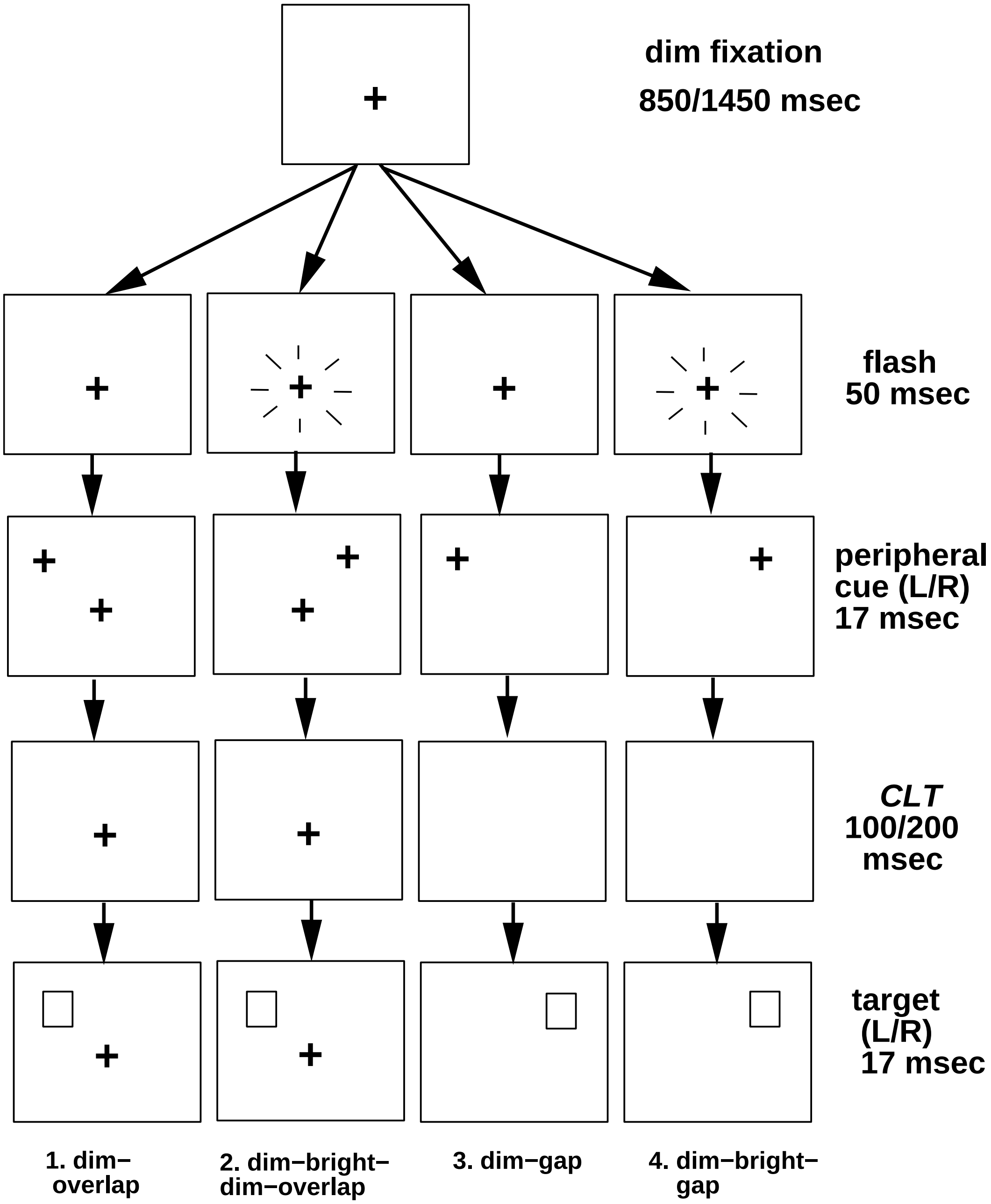


Fig. 4.

Tanaka & Shimojo

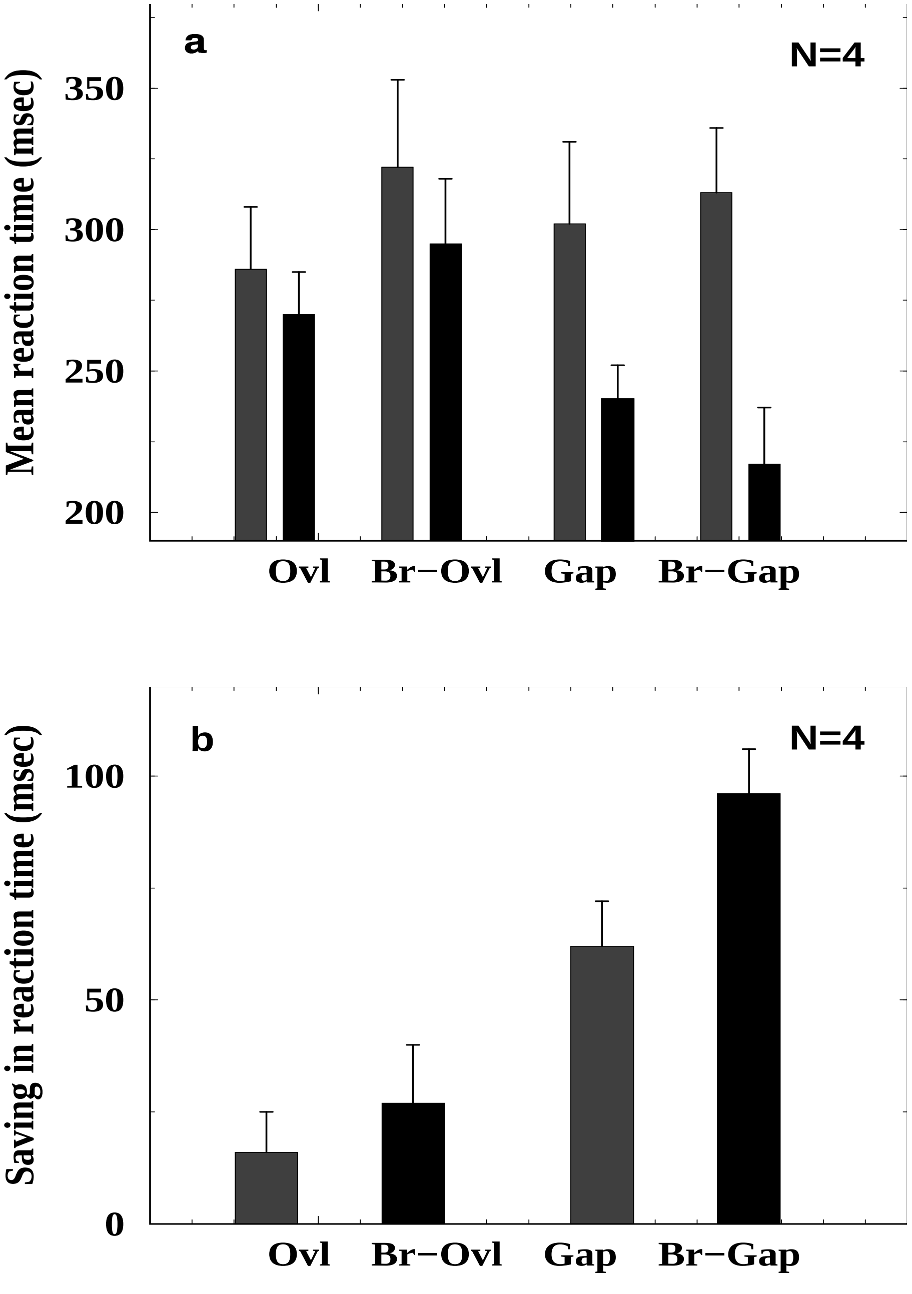


Fig. 5.

Tanaka & Shimojo

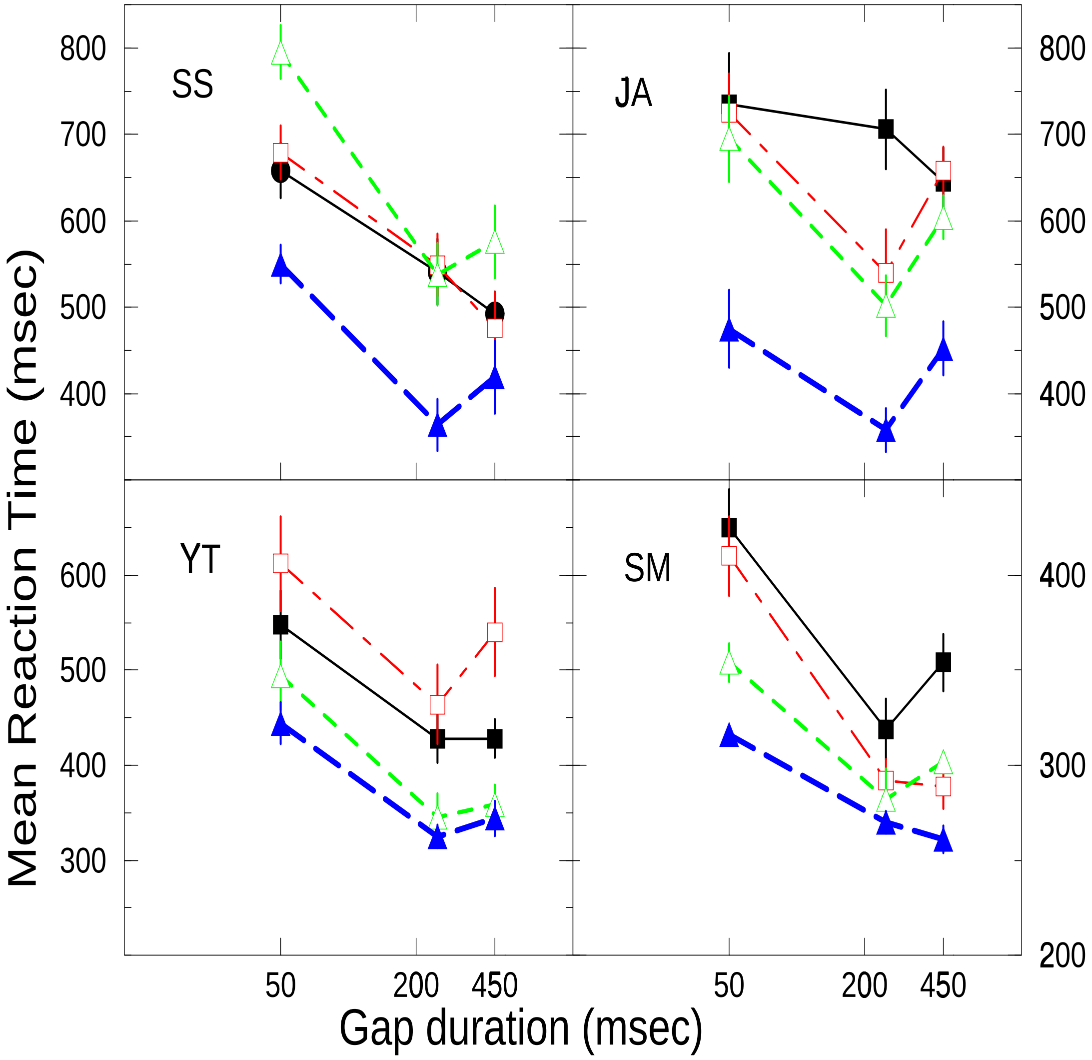
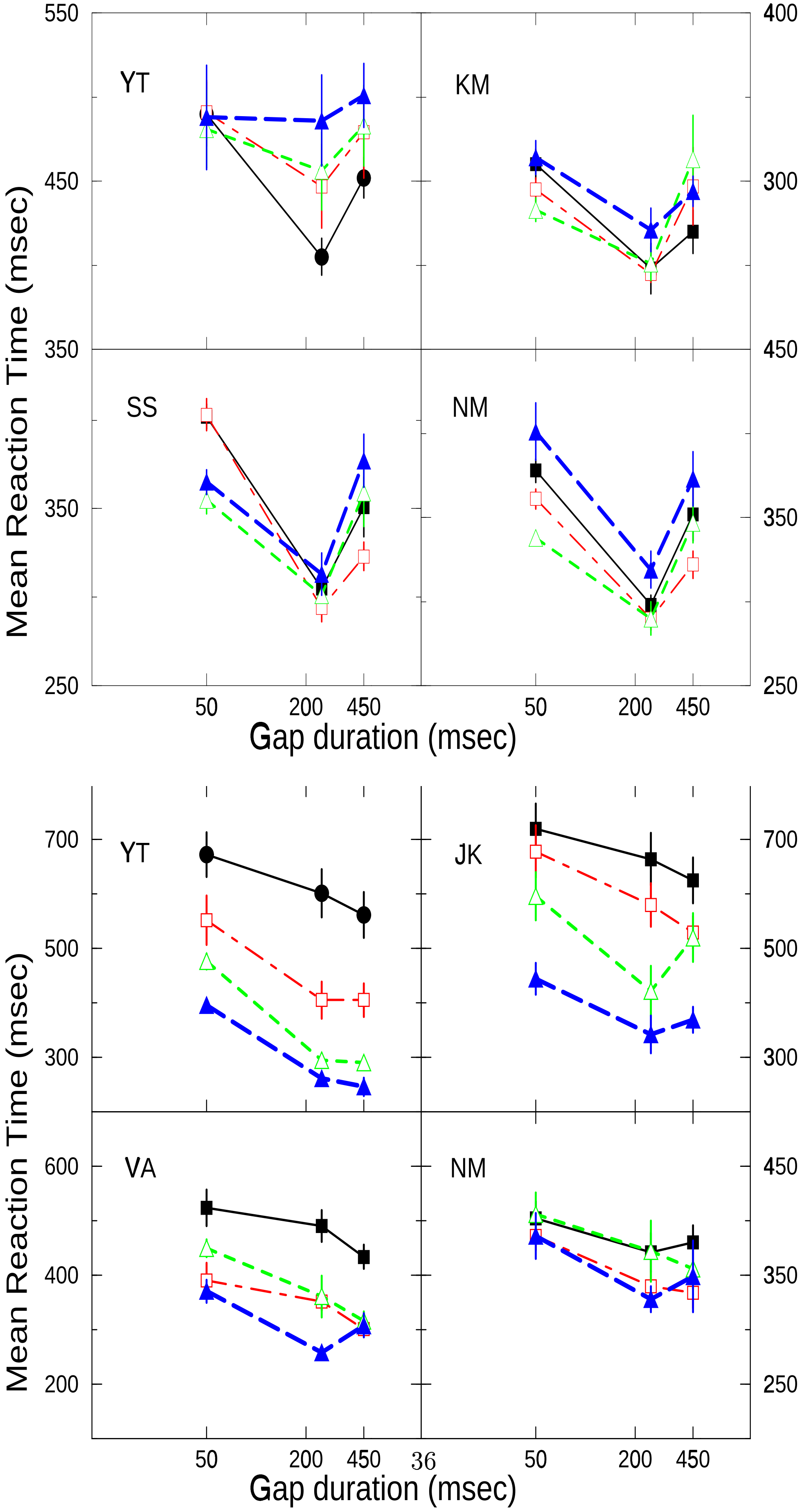


Fig. 6.

Tanaka & Shimojo


YT
KM
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Mean Reaction Time (msec)
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Gap duration (msec)
YT
JK
VA
NM
700
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600
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350
250
Mean Reaction Time (msec)
50
200
450
Gap duration (msec)

Fig. 7.