

Fixation offset facilitates saccades and manual reaching for single but not multiple target displays

Joo-Hyun Song · Ken Nakayama

Received: 28 February 2006 / Accepted: 1 August 2006 / Published online: 1 September 2006
© Springer-Verlag 2006

Abstract Turning off a fixation point, typically for 200 ms, before the onset of a peripheral target substantially reduces saccadic reaction times. This facilitatory effect generated by an inserted temporal gap between fixation offset and the target appearance is called the “gap” effect [J Opt Soc Am 57:1030–1033, 1967]. We show that the gap reduces the initial latency of both saccades and manual pointing in single and multiple target displays. Yet, in multiple target displays, the gap increased the movement duration because eye or hand movements were frequently misdirected toward distractors so that the trajectory had to be corrected. Thus, in spite of the shortened latency, the total time for trial completion was not shortened in multiple target displays, whereas it was reduced in single target displays. This selective gap effect for a single target was not restricted to goal-directed motor tasks because perceptual discrimination tasks, where no motor response is required, also demonstrated the gap effect only for single target displays. Our results suggest that the gap may facilitate attentional disengagement, but it does not help target selection in motor and perceptual discrimination tasks, where the allocation of attention to the target is required.

Keywords Gap effect · Saccades · Manual pointing · Perceptual discrimination · Attention

J.-H. Song (✉)
Department of Psychology, Harvard University,
33 Kirkland Street, WJH 710, Cambridge, MA 02138, USA
e-mail: jhsong@ski.org

K. Nakayama
Department of Psychology, Harvard University,
33 Kirkland Street, WJH 770, Cambridge, MA 02138, USA

Introduction

Saccadic eye movements generally occur with a very short latency of approximately 200 ms. Surprisingly, turning off a fixation point for about 200 ms before the saccadic target is presented can substantially shorten saccadic onset latencies. This latency facilitatory effect produced by inserting a temporal gap is called the “gap” effect (Saslow 1967).

The gap effect has been explained as a combination of a general warning and an oculomotor specific facilitation effect (Kingstone and Klein 1993; Reuter-Lorenz et al. 1995; Pratt et al. 2000). The fixation removal provides a general warning as to the onset of stimulus, and also releases the inhibition of the fixation cells in the rostral pole of the superior colliculus. The fixation cells suppress eye movements to maintain stationary positions. Single cell recordings in monkeys showed that the discharge rate of fixation cells were reduced when a 200–300 ms temporal gap was presented (Munoz and Wurtz 1993; Dorris and Munoz 1995).

The gap effect, thus, has been typically studied with saccades (Fischer and Ramsperger 1984; Mayfrank et al. 1986; Fischer and Breitmeyer 1987; Weber and Fischer 1995) but some studies examined gap effects with manual responses such as reaching or key press. Early studies were not entirely conclusive. Small gap effects for manual responses were sometimes observed, but this effect disappeared when the auditory warning control was presented (Tam and Ono 1994; Reuter-Lorenz et al. 1995). Thus these early studies could not rule out an explanation based on a general warning effect alone.

More recently, however, Bekkering et al. (1996) demonstrated a reliable gap effect for manual responses, controlling for the warning explanation by

presenting an auditory cue signaling stimulus onset in all conditions. They also conjectured that previous studies failed to show consistent manual gap effects because this effect may be specific to spatially oriented movements. Consistent with their idea, reliable gap effects were found for direct reaching to the target but not for simple key press. These results support the idea that goal-oriented responses are essential for manual gap effects. In addition, Pratt et al. (1999) demonstrated that both saccadic and manual pointing reaction times were similarly affected by the duration of the gap. These results demonstrate that the gap effect is not restricted to eye movements. Furthermore, single cell recording data also shows correlated superior colliculus activity known for controlling eye movements with aimed hand movements (Werner 1993), raising the possibility that the manual gap effect could also be attributed to the properties of neurons in the superior colliculus (Bekkering et al. 1996; Pratt et al. 1999).

Perceptual gap effects have also been found in studies of attentional deployment. The presence of a temporal gap leads to more accurate or faster perceptual discrimination of cued targets (Mackeben and Nakayama 1993; Pratt and Nghiem 2000). In these studies, the results were interpreted in terms of attentional disengagement, a process postulated by Posner (1980) to account for the sequence of events required for a saccadic eye movement. It begins with (1) attentional disengagement from the object attended to, (2) moving attention to the new point of interest, (3) engaging attention there, (4) releasing eye fixation from the previous object, (5) moving the eyes, and (6) finally re-engaging eye fixation. Adopting this framework, Fischer (1987) argued that the “gap” or fixation disappearance assisted only in the first step of this process, i.e., attentional disengagement. When the fixation stimulus is removed, attentional engagement is automatically released from the current object, bypassing this first step and speeding saccades.

In the current study, our interest is to understand how a temporal gap affects goal-directed reaching, saccades and perceptual discrimination tasks when subjects are required to select a target among competing distractors. To anticipate, we confirmed previous results indicating a clear gap effect when only one target was present and no selection is required. This alone, however, does not deal with the selection issue. Because Fischer’s (1987) account pinpoints the gap effect to a single stage of attentional disengagement it does not predict any performance advantages for the subsequent stages required to make a directed movement. Thus, according to this view, the gap should confer no benefit in terms of attentional selection or subsequent motor responses. To

examine this in detail, we measured not just the initial latency, but also the full trajectory of the motor response. Goal-directed actions are closely coupled with allocation of focused attention so we could examine how attentional selection or other motor responses might evolve over time (see Corbetta et al. 1998; Castiello 1999; Schall and Thompson 1999 for reviews).

We performed three experiments. First, we replicated the gap effect for both saccades and manual pointing with single target displays. Second, we examined the gap effect for multiple target displays using an odd-colored target search task, which has been widely used for both humans (Bravo and Nakayama 1992; Maljkovic and Nakayama 1994; McPeck et al. 1999) and monkeys (Bichot and Schall 1999; McPeck and Keller 2001; Arai et al. 2004). We presented the odd-colored target with two distractors to create target-distractor competition. Third, we examined the gap effect for perceptual discrimination with single and multiple targets displays, investigating the more general role of the gap when shift of focused attention to the target is required but in the absence of motor responses (Bravo and Nakayama 1992; Maljkovic and Nakayama 1994).

General methods

Subjects

Harvard University students participated for course credit. They were all right-handed with normal color vision and normal visual acuity. Five subjects participated in the first two studies of saccade and manual pointing, and twelve new subjects participated in the third perceptual discrimination study. All experimental procedures were approved by the Harvard University Institutional Review Board.

Stimuli

The stimuli were solid, red or green colored diamond-shaped figures subtending $1.5^\circ \times 1.5^\circ$ against a black background. Red and green were set to equiluminance with flicker photometry. The visual display was back projected on the upright plexi-glass screen ($43 \times 35 \text{ cm}^2$). All visual display and data recording were controlled by Power Mac G4 using Vision Shell.

Procedure

Subjects were tested individually in a semi-darkened room and their heads were stabilized with a chin-rest. They were seated 48 cm in front of the screen. The

fixation point was presented on the screen for 700 ms (Fig. 1). The fixation point disappeared (*gap* condition) or remained (*overlap* condition) for 200 ms. Since several studies have shown in saccadic tasks that saccades that a general warning effect can explain 35–50% of the gap effects (Reuter-Lorenz et al. 1995; Pratt et al. 2000), we always presented an auditory warning in all trials before the stimulus onset in order to control a general warning effect across conditions (Bekkering et al. 1996). *Gap* and *overlap* trials were randomly intermixed with equal probability. The stimulus display was presented on the screen. Subjects performed saccades, manual pointing, or perceptual discrimination. The display remained on until subjects responded. Auditory feedback was provided to inform whether subjects touched the correct target. The intertrial interval was 1,000 ms. Subjects were instructed to respond to the target as quickly and accurately as possible.

Measuring eye and hand movements

The eye movements were recorded with a head-mounted infrared eye tracker (Eye Link II) with an update rate of a 250 Hz.

Hand movements were tracked with a Fastrak electromagnetic position and orientation measuring system

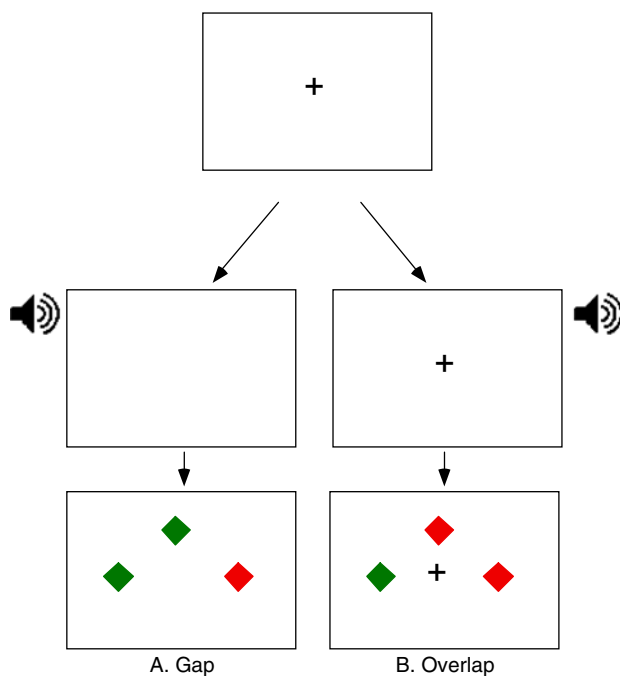


Fig. 1 Schematic diagram of experimental procedure. A trial started with presenting 700 ms fixation point. The fixation point disappeared (*gap* condition) or remained on (*overlap* condition) for 200 ms. At the beginning of both gap and overlap period, a beep was presented to control for a warning effect. Then, stimuli were presented until subjects responded

(Polhemus Inc., Colchester, VT, USA) with an update rate of a 120 Hz. The small position-tracking sensor ($0.89'' \times 0.50'' \times 0.45''$) was attached on the index fingertip of the right hand. The starting position ($3 \times 3 \text{ cm}^2$) was defined on the table, which was approximately aligned with the body midline and 20 cm in front of subjects.

Subjects were required to fixate on the center and put their index finger on the starting position to initiate each trial. Both measurement systems were calibrated every 20 trials with nine distributed points.

Data analysis

Movement data were transmitted to Power Mac G4 by Vision Shell library for off-line analysis to identify the onset and offset of movements. Eye velocity exceeding a threshold of $30^\circ/\text{s}$ and hand velocity exceeding a threshold of 10 cm/s demarcated movement. Each trajectory was visually inspected to verify the appropriateness of these criteria, which were adjusted by hand if necessary.

Initiation latency for eye and hand movements was defined as an interval between the stimulus and movement onsets. Saccadic latency below 80 ms or hand latency below 100 ms was considered as an anticipatory movement and excluded from analysis. Less than 3% of the trials were removed using this criterion. *Movement duration* was the interval between the movement onset and termination at the target. Intersaccadic intervals between initial and corrective saccades were included for movement duration measures. *Total time* was the simple sum of *initiation latency* and *movement duration*.

Experiment 1: saccadic and manual gap effects with single target

In Experiment 1, we examined the gap effect for both saccades and manual-pointing movements with single target displays. The aim was to confirm the existence of the manual gap effect in a direct reaching task in order to show that the gap effect is not oculomotor specific (Bekkering et al. 1996; Pratt et al. 1999).

Methods

Procedure

On each trial, the single red or green diamond was presented randomly either 18° left or right of the center on the screen. In a separate block, subjects were asked to make 60 saccades, or 60 manual-pointing movements to the target. In the manual-pointing task, subjects

were asked to look at the center though the fixation point disappeared in some (gap) trials. Trials in which subjects made saccadic eye movements were excluded from analysis. Less than 2% of the trials were removed by this criterion.

Results and discussion

Results in Fig. 2 show that initiation latencies were shorter for the *gap* compared to the *overlap* condition for both saccades (Fig. 2a), $t(4) = 4.2$, $p < 0.02$, and manual-pointing (Fig. 2b), $t(4) = 3.8$, $p < 0.02$. *Total time* was also shorter for the *gap* than the *overlap* condition for both saccades (273 ± 12.5 ms vs. 300 ± 12.3 (SEM) ms), $t(4) = 3.35$, $p < 0.03$, and manual-pointing (625 ± 25.5 ms vs. 693 ± 20.7 (SEM) ms), $t(4) = 10.3$, $p < 0.001$. Therefore, we replicated previous studies showing the gap effect for both saccades and hand movement with a single target display, and confirmed that the gap effect is not specific to the oculomotor system (Bekkering et al. 1996; Pratt et al. 1999).

It should be noted that while we see a consistent gap effect here and later in this paper, the size of the effect is smaller than some others reported in the literature (Saslow 1967; Fischer and Ramsperger 1984). As mentioned earlier, because a significant fraction of the gap effect is due to the warning effect provided by fixation offset, smaller effects are expected in our case when an auditory warning signal is presented in all trials (Reuter-Lorenz et al. 1995; Pratt et al. 2000).

Experiment 2: saccadic and manual gap effects with multiple targets

In Experiment 1, we observed reliable gap effects in both saccadic and manual pointing tasks with single

target displays. With single target displays, eye and hand movements are directed to the correct target since there is no competing stimulus. Yet, natural environments typically contain more than one object and a specific target must be selected among them for action. With multiple targets, we asked how the gap would influence the entire course of motor behavior. To address these questions, we measured not just the initial latency as in other studies but the full trajectory of the motor response.

Methods

Procedure

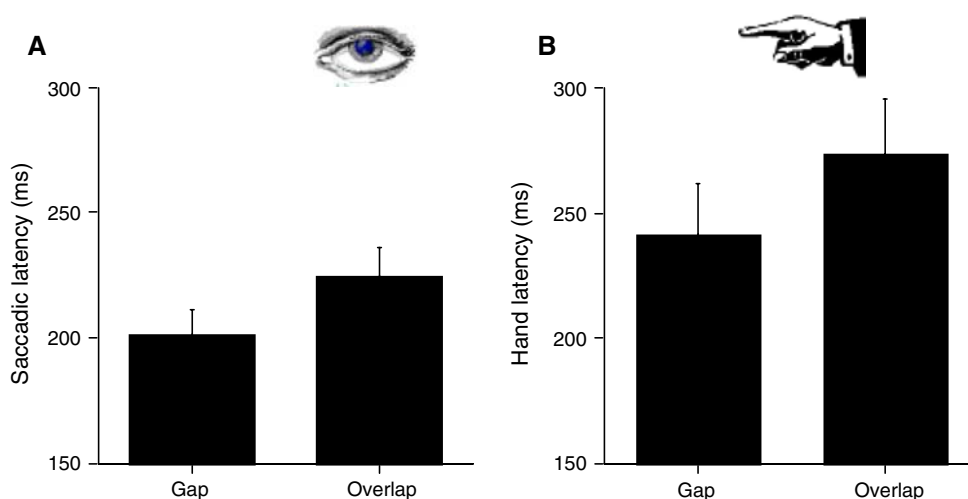
On each trial, instead of a single target, one red and two green diamonds, or one green and two red diamonds were randomly presented. The stimuli were arranged 18° left and right and 10° above the center fixation on the screen. The target was the odd-colored diamond located on either left or right side. In order to examine the interaction between saccades and reaching, we also included the task requiring both saccades and reaching toward the same target. Thus, subjects performed two blocks (40 trials/block) each of the following tasks: saccade only (separate task), manual-pointing only (separate task) and both saccade and manual-pointing (concurrent task). The order of the each block was randomly assigned across subjects.

Results and discussion

Initiation latency

As with a single target, the gap facilitated the initiation latency of both saccades (Fig. 3a) and manual pointing (Fig. 3b) with multiple targets. This was confirmed by

Fig. 2 Initial latencies of saccades (a) and manual pointing (b) for *gap* and *overlap* conditions with a single target in Experiment 1. The error bar shows between subjects standard errors



2(task type: separate versus concurrent) \times 2(trial type: gap versus overlap) repeated ANOVA. Saccadic latencies for *gap* trials were significantly shorter than those of *overlap* trials, $F(1,4) = 9.7$, $p < 0.05$. There was no significant difference between separate and concurrent tasks, $F(1,4) = 1.52$, $p > 1$, and no interaction between task and trial types, $F < 1$.

Manual-pointing latencies for *gap* trials were also significantly shorter than those of *overlap* trials, $F(1,4) = 19.38$, $p < 0.02$, showing that the manual gap effect occurs reliably in a wide variety of conditions. There was marginally significant difference between *separate* and *concurrent* tasks, $F(1,4) = 5$, $p < 0.06$, and no interaction between task, and trial types, $F < 1$.

Trajectory

With multiple target displays, we consistently showed that the gap again facilitated initial latencies for both saccades and manual pointing. Thus, we further confirm that the gap effect is not oculomotor specific, and provide more evidence that the gap facilitates attentional disengagement. However, the results so far do not address the issue as to whether subsequent target selection stages are also facilitated.

Figure 4 shows an example of saccadic trajectories from a single subject. In Fig. 4a the upper traces showed movements that should be directed to the target on the right, the lower directed to the left. In each case, there were a substantial number of saccades in the wrong direction. This contrasted to the case of the *overlap* condition (Fig. 4b) where only one mistake was

observed. The same pattern of initially misdirected movements can also be seen for manual pointing as depicted in Fig. 5. Subjects typically initiated their reaching movements toward distractors and corrected them to the target more often in the gap condition (Fig. 5a) as compared to the overlap condition (Fig. 5b).

The striking difference in trajectories is seen in all subjects and indicates that the quicker initial response of the eye and hand has costs. Quick attentional disengagement, while seemingly beneficial in getting the movement started more quickly, may not allow enough time for the correct target to be selected. Assuming that attention precedes goal directed motor movements (Song and Nakayama in press; Deubel and Schneider 1996; Schiegg et al. 2003), it indicates that the deployment of attention is misdirected initially and then corrected.

Movement duration

With a greater number of initial trajectories directed to the wrong target, it should not be surprising that there should be some evident costs in terms of movement duration. Therefore, we predicted longer movement duration in gap trials than overlap trials. In accord with our prediction, *gap* trials showed longer movement durations than *overlap* trials in both saccade (105.2 ± 6.3 ms vs. 94.7 ± 5.8 (SEM) ms), $F(1,4) = 7.1$, $p < 0.03$ (*one-tailed*), and pointing tasks (413.9 ± 22.6 ms vs. 347.5 ± 10.2 ms), $F(1,4) = 16.6$, $p < 0.02$. Therefore, there was a significant interaction

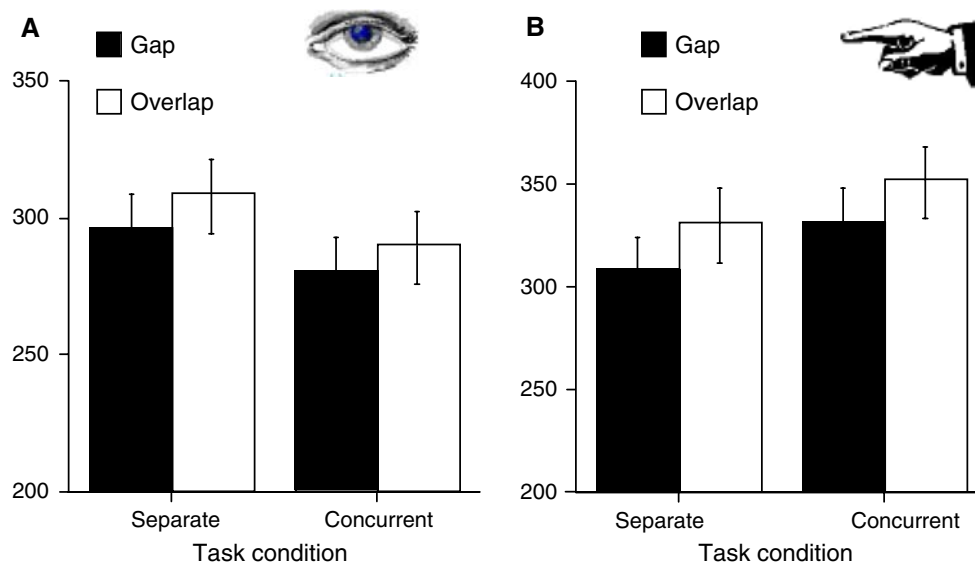


Fig. 3 Initial latencies of saccades (a) and manual pointing movements (b) for *gap* and *overlap* conditions in separate and concurrent tasks with multiple target displays in Experiment 2. The error bar shows between subjects standard errors

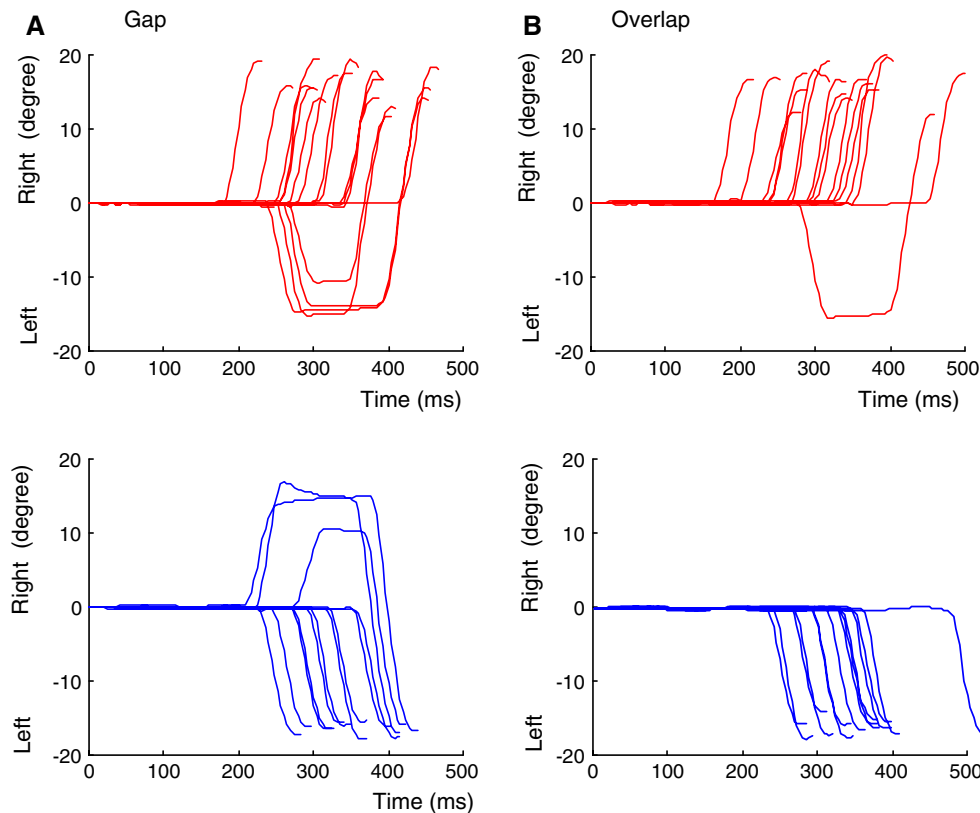


Fig. 4 An example of saccadic trajectories from a subject in the *gap* (a) and *overlap* (b) conditions from the concurrent condition in Experiment 2. Trajectories associated with each target location

are depicted by two distinct colors: left position (*blue*) and right (*red*)

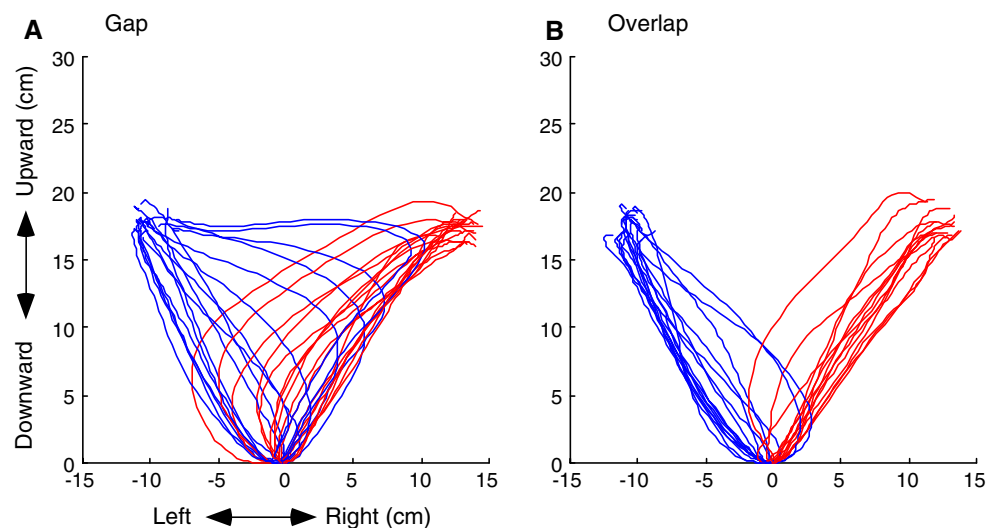


Fig. 5 An Examples of manual-pointing trajectories in the *gap* (a) and *overlap* (b) conditions from a single subject from the concurrent condition in Experiment 2. Trajectories associated with each target location are depicted by two distinct colors: left posi-

tion (*blue*) and right (*red*). These trajectories are three dimensional, but for clarity we only show the *X* and *Y* dimensions where the greatest difference between trajectory types is most evident

effect between the movement index (latency versus duration) and trial type (*gap* versus *overlap*) in both saccade, $F(1,4) = 23.1$, $p < 0.005$, and manual pointing, $F(1,4) = 51.12$, $p < 0.002$. Thus there is a cost for early

attentional disengagement in the *gap* condition. Attention can be directed to the wrong target with subsequent errors in the initial visually guided response.

Total time

It is of interest to see the net consequence of these two opposing tendencies, the faster initial responses accompanied by greater errors and consequent longer movement durations. We compared the *total time*, combining *initial latency*, and *movement duration*, in the *gap* and *overlap* trials. The *total time* of the *gap* condition did not differ that of the *overlap* condition in both saccadic, $F < 1$ and manual-pointing tasks, $F(1,4) = 2.89$, $p > 0.2$. The facilitatory gain of the *gap* in initial latency has thus vanished for the multiple target condition. Because the gap leads to an initial misdirection of faster motor response, it does not lead to more adaptive behavior when target selection is required.

Experiment 3: gap effect for perceptual discrimination without a required movement

With multiple target displays, we showed that the gap elicits shorter saccadic and manual-pointing latencies at the cost of time-consuming misdirected movements. Thus, we did not observe overall facilitatory effect produced by the gap for trial completion. As we described, this selective gap effects across saccades and manual pointing can be explained by a very specific role for focal attention, namely its disengagement.

To provide independent confirmation of this idea, we turn to a perceptual discrimination task under a similar range of conditions. Rather than asking for a goal-directed response, we simply asked subjects to discriminate a subtle target feature. In this task, the shift of focal attention to the target is necessary to perform perceptual discrimination of a fine target feature (Bravo and Nakayama 1992; Maljkovic and Nakayama 1994).

On each trial, each diamond had a tiny cut-off corner ($0.15^\circ \times 0.15^\circ$) on either left or right side. Subjects were required to report the cut-off side of the target by pressing “j” (left) or “k” (right) key. In the single target case, subjects determined whether a single diamond is cut off on the left or right. In the multiple target case, they reported a cut-off side of an odd-colored target.

Subjects performed a single task first and then a multiple task (each 80 trials). They were asked to look at the center though the fixation point disappeared in some (*gap*) trials. Trials in which subjects made saccades, or in which reaction times were longer than 1.3 s, were not included in data analysis. These criteria removed less than 2% of trials. Accuracy rates in all conditions were overall 95% and there was no speed-accuracy trade-offs, $F_s < 1$.

If attentional disengagement is operative similarly for this discrimination task, we can make a series of predictions. First, the gap should facilitate perceptual discrimination in the single target case because it leads to faster disengagement and subsequent engagement to the single lone target. With multiple targets, however, we expect that rapid disengagement of attention will be accompanied by incorrect attentional selection as we have demonstrated in the two motor tasks. Thus the benefit of the gap will be lost or diminished for this condition. Results in Fig. 6 confirmed this prediction. Overall, reaction times in the single target task were shorter than those in the multiple target task, $F(1,11) = 59.76$, $p < 0.001$. There was a significant interaction effect between the task type (single versus multiple) and trial type (gap versus overlap), $F(1,11) = 5.67$, $p < 0.04$. In details, Fig. 6 demonstrates that the gap effect significantly improved performance in the single target task, $t(11) = 3.25$, $p < 0.01$. However, there was no gap effect in the multiple target task $t(11) = 0.48$, $p < 1$. This mirrors results of the *total time* in saccadic and manual-pointing tasks, which demonstrates that the gap can facilitate response initiation but not target selection.

General discussion

We demonstrated that the gap reliably reduces saccadic, and manual-pointing latencies as well as discrimi-

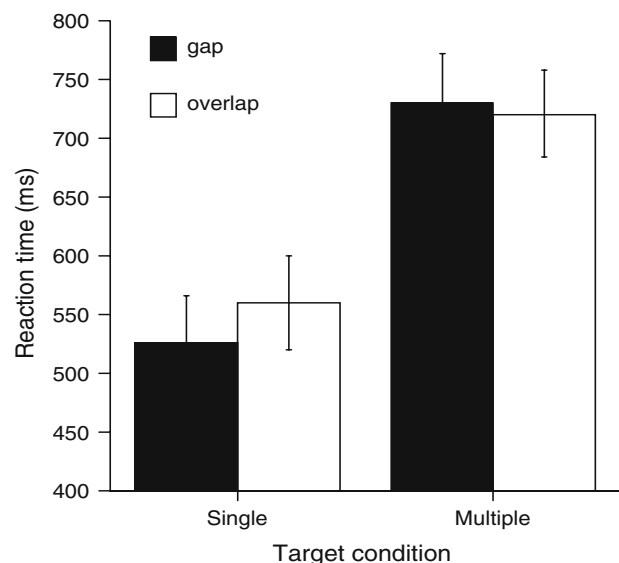


Fig. 6 Reaction times of *gap* and *overlap* conditions with single and multiple target displays in perceptual discrimination tasks in Experiment 3. The *error bar* shows between subjects standard errors

nation reaction times when a single target is presented. These results are consistent with previous studies showing that the gap effect is not specific to the oculomotor system (Bekkering et al. 1996; Pratt et al. 1999). However, with multiple targets, the gap shortens saccadic and manual-pointing latencies but not movement durations because it increases a number of movements misdirected to distractors, requiring subsequent time-consuming online correction. Thus when movement initiation is facilitated by the gap, there are costs of lengthened trajectory path and movement duration. The gap does not aid target selection after movement initiation.

More importantly, recent neuroimaging and neurophysiological studies have established the link between visually guided goal directed actions and visual attention. Saccades and covert attention allocation activate common regions of the brain, such as frontal eye field, supplementary eye field and several parietal and temporal regions (see Corbetta et al. 1998; Schall and Thompson 1999 for reviews). Behavioral studies also showed that attention allocation to the target precedes saccades (Kowler et al. 1995; Deubel and Schneider 1996; McPeck et al. 1999; Schneider and Deubel 2002), and manual reaching (Schiegg et al. 2003). The locus of attention also affects the trajectory of saccades (Sheliga et al. 1995) and reaching movements (Tipper et al. 1992; Castiello 1999; Song and Nakayama in press). The necessity of the focal attention allocation for perceptual discrimination is also demonstrated (Bravo and Nakayama 1992; Mackeben and Nakayama 1993; Maljkovic and Nakayama 1994).

Thus we connected results from motor tasks with stages of attention allocation. We suggest that the gap facilitates a release of the focused attention from the fovea, allowing faster attentional disengagement (Fischer 1987). Yet, this rapid disengagement does not reduce the duration of subsequent attentional selection when multiple targets are presented. We argue that early disengagement occurring before the target selection is finalized often shifts attention toward one of activated “wrong” stimuli. More time is consumed to redirect attention to the correct target. With multiple targets, therefore, the gap shortens saccadic and manual-pointing latencies but not movement durations. Curved trajectories with longer movement duration in motor tasks reflect this attention re-directing process. Consequently, when the *total time* for completion is considered, the facilitatory gap effect is limited to single target displays. We acknowledged that although our study demonstrated the lack of the gap effect in total time, the overall gap effect could have a range of magnitudes depending on features of the stimuli and of

the task rather than all-or-none. For instance, depending on the trade-off between shortened initial latency and lengthened movement duration, the total effect could be changed on the continuum. However, the critical finding in the current study is that the temporal gap facilitates only disengagement of but not redirection of attention. Analysis of the movements after onset provided some additional insights, which cannot be easily seen in discrete tasks.

Perceptual discrimination task without goal-directed motor responses provided additional converging evidence that the gap facilitates selectively attention disengagement but not redirection. With a single target discrimination task, we observed a reliable gap effect as in saccades and hand movements. It confirms previous findings that facilitated attention disengagement by the gap can reduce reaction times (Mackeben and Nakayama 1993; Pratt and Nghiem 2000). This also demonstrated that the gap effect affect non-spatial discrimination keypress reaction times, which is more general than previously demonstrated (Bekkering et al. 1996) as long as focal attention is localized to the specific target site (Bravo and Nakayama 1992; Maljkovic and Nakayama 1994).

When multiple stimuli were presented for discrimination, however, the gap effect disappeared. This is consistent with idea that focal attention, while released more quickly by the gap, is more prone to be misdirected to a distractor and redirected to the target. In contrast to goal-directed action tasks, where we could analyze the gap effect in more detail, we can only examine completed reaction times in perceptual tasks so that it is more difficult to directly assess selective influences of the temporal gap in perceptual tasks beyond evaluating overall gap effects. However, three very different tasks (saccades, reaching, and perceptual discrimination) provide consistent and converging information that the fixation release (the gap) facilitates attentional disengagement only. As a consequence, the gap facilitates task performance only in the single but not multiple item case.

Recent neurophysiological studies have shown that the superior colliculus is related to attentional deployment and target selection (see Schall 2001 for review). McPeck and Keller (2002, 2004) demonstrated that when monkeys were required to make saccades to an odd-colored target among distractors while chemical lesions temporarily inactivated just one retinotopic locus in the superior colliculus, saccades to the target in inactivated field were misdirected to distractors. Also, multiple competing stimuli are represented simultaneously and accumulated information gradually strengthens one over the others in the superior collicu-

lus. For instance, McPeck et al. (2003) showed that with multiple target displays, curved saccades toward a distractor were accompanied by increased presaccadic activity of neurons coding the distractor site in the superior colliculus. These results support that the superior colliculus is also involved in target selection process, closely associated with the deployment of the focal attention to the target, which can be compatible with the attentional account of our results.

To conclude, in the current study, we demonstrated that when a temporal gap is inserted between fixation point offset and stimulus onset, the initiation of saccade and manual-pointing is facilitated in both single and multiple target displays. This supports the view that the gap effect is not limited to saccades nor to single target arrays. Yet, with multiple target displays, this speeded onset comes with the cost of misdirected movements, requiring corrective movements.

Acknowledgments JHS is supported by Korea Foundation For Advanced Studies fellowship. We thank Charles Stromeyer III, Yuhong Jiang, Amelia Hunt, and Dr. Richard Abrams for helpful comments.

References

- Arai K, McPeck RM, Keller EL (2004) Properties of saccadic responses in monkey when multiple competing visual stimuli are present. *J Neurophysiol* 91:890–900
- Bekkering H, Pratt J, Abrams RA (1996) The gap effect for eye and hand movements. *Percept Psychophys* 58(4):628–635
- Bichot NP, Schall JD (1999) Effects of similarity and history on neural mechanisms of visual selection. *Nat Neurosci* 2:549–554
- Bravo MJ, Nakayama K (1992) The role of attention in different visual-search tasks. *Percept Psychophys* 51:465–472
- Castiello U (1999) Mechanisms of selection for the control of hand action. *Trends Cogn Sci* 7:264–271
- Corbetta M, Akbudak E, Conturo TE, Snyder AZ, Ollinger JM, Drury HA, Linenweber MR, Petersen SE, Raichle ME, Van Essen DC, Shulman GL (1998) A common network of functional areas for attention and eye movements. *Neuron* 21(4):761–773
- Deubel H, Schneider WX (1996) Saccade target selection and object recognition: evidence for a common attentional mechanism. *Vision Res* 36:1827–1837
- Dorris MC, Munoz DP (1995) A neural correlate for the gap effect on saccadic reaction times in monkey. *J Neurophysiol* 73:2258–2562
- Fischer B (1987) The preparation of visually guided saccades. *Rev Physiol Biochem Pharmacol* 106:1–35
- Fischer B, Breitmeyer B (1987) Mechanisms of visual attention revealed by saccadic eye movements. *Neuropsychologia* 25(1A):73–83
- Fischer B, Ramsperger E (1984) Human express saccades: extremely short reaction times of goal directed eye movements. *Exp Brain Res* 57(1):191–195
- Kingstone A, Klein R (1993) Visual offset facilitates saccadic latency: does pre-disengagement of visuo-spatial attention mediate this gap effect? *J Exp Psychol Hum Percept Perform* 19:1251–1265
- Kowler E, Anderson E, Doshier B, Blaser E (1995) The role of attention in the programming of saccades. *Vision Res* 35:1897–1916
- Mackeben M, Nakayama K (1993) Express attentional shifts. *Vision Res* 33:85–90
- Maljkovic V, Nakayama K (1994) Priming of popout: I. Role of features. *Mem Cognit* 22:657–672
- Mayfrank L, Mobashery M, Kimming H, Fischer B (1986) The role of fixation and visual attention in the occurrence of express saccades in man. *Eur Arch Psychiatry Neural Sci* 235:269–275
- McPeck RM, Han JH, Keller EL (2003) Competition between saccade goals in the superior colliculus produces saccade curvature. *J Neurophysiol* 89:2577–2590
- McPeck RM, Keller EL (2001) Short-term priming, concurrent processing, and saccade curvature during a target selection task in the monkey. *Vision Res* 41(6):785–800
- McPeck RM, Keller EL (2002) Saccade target selection in the superior colliculus during a visual search task. *J Neurophysiol* 88:2019–2034
- McPeck RM, Keller EL (2004) Deficits in saccade target selection after inactivation of superior colliculus. *Nat Neurosci* 7:757–763
- McPeck RM, Maljkovic V, Nakayama K (1999) Saccades require focal attention and are facilitated by a short-term memory system. *Vision Res* 39:1555–1566
- Munoz DP, Wurtz RH (1993) Fixation cells in monkey superior colliculus. I. Characteristics of cell discharge. *J Neurophysiol* 70:559–575
- Posner MI (1980) Orienting of attention. *Q J Exp Psychol* 32:3–25
- Pratt J, Bekkering H, Leung M (2000) Estimating the components of the gap effect. *Exp Brain Res* 130(2):258–263
- Pratt J, Bekkering H, Abrams RA, Adam J (1999) The gap effect for spatially oriented responses. *Acta Psychol* 102:1–12
- Pratt J, Nghiem T (2000) The role of the gap effect in the orienting of attention: evidence for express attentional shifts. *Vis Cogn* 5:629–644
- Reuter-Lorenz PA, Oonk H, Barnes L, Hughes HC (1995) Effects of warning signals and fixation point offsets on the latencies of pro- vs. anti- saccades: implications for an interpretation of the gap effect. *Exp Brain Res* 103:287–293
- Saslow MG (1967) Effects of components of displacement-step stimuli upon latency for saccadic eye movement. *J Opt Soc Am* 57:1030–1033
- Schall JD (2001) Neural basis of deciding, choosing, and acting. *Nat Rev Neurosci* 2:33–42
- Schall JD, Thompson KG (1999) Neural selection and control of visually guided eye movements. *Annu Rev Neurosci* 22:241–259
- Schiegg A, Deubel H, Schneider WX (2003) Attentional selection during preparation of prehension movements. *Vis Cogn* 10(4):409–431
- Schneider WX, Deubel H (2002) Selection-for-perception and selection-for-spatial-motor-action are coupled by visual attention: a review of recent findings and new evidence from stimulus-driven saccade control. In: Prinz W, Hommel B (eds) *Attention and performance XIX: common mechanisms in perception and action*. Oxford University Press, Oxford
- Sheliga BM, Riggio L, Craighero L, Rizzolatti G (1995) Spatial attention-determined modifications in saccade trajectories. *Neuroreport* 6:585–588
- Song J-H, Nakayama K (in press) Role of focal attention on latencies and trajectories of visually-guided manual pointing. *J Vis*

- Tam W, Ono H (1994) Fixation disengagement and eye movement latency. *Percept Psychophys* 56:251–260
- Tipper SP, Lortie C, Baylis GC (1992) Selective reaching: evidence for action-centered attention. *J Exp Psychol Hum Percept Perform* 18:891–905
- Weber H, Fischer B (1995) Gap duration and location of attention focus modulate the occurrence of left/right asymmetries in the saccadic reaction times of human subjects. *Vision Res* 35(7):987–998
- Werner W (1993) Neurons in the primate superior colliculus are active before and during arm movements to visual targets. *Eur J Neurosci* 5:335–340