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Contributions of retinal input and phenomenal representation of a fixation object to the saccadic gap effect

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ABSTRACT

The saccadic "gap effect" refers to a phenomenon whereby saccadic reaction times (SRTs) are shortened by the removal of a visual fixation stimulus prior to target presentation. In the current study, we investigated whether the gap effect was influenced by retinal input of a fixation stimulus, as well as phenomenal permanence and/or expectation of the re-emergence of a fixation stimulus. In Experiment 1, we used an occluded fixation stimulus that was gradually hidden by a moving plate prior to the target presentation, which produced the impression that the fixation stimulus still remained and would reappear from behind the plate. We found that the gap effect was significantly weakened with the occluded fixation stimulus. However, the SRT with the occluded fixation stimulus was still shorter in comparison to when the fixation stimulus physically remained on the screen. In Experiment 2, we investigated whether this effect was due to phenomenal maintenance or expectation of the reappearance of the fixation stimulus; this was achieved by using occluding plates that were an identical color to the background screen, giving the impression of reappearance of the fixation stimulus but not of its maintenance. The result showed that the gap effect was still weakened by the same degree even without phenomenal maintenance of the fixation stimulus. These results suggest that the saccadic gap effect is modulated by both retinal input and subjective expectation of re-emergence of the fixation stimulus. In addition to oculomotor mechanisms, other components, such as attentional mechanisms, likely contribute to facilitation of the subsequent action.

1. Introduction

Visual events occurring at a fixated location can influence the subsequent action taken. If a fixation stimulus disappears shortly before the presentation of a peripheral target, the saccadic response to the target is faster than if the fixation stimulus remained. This phenomenon was first reported by Saslow (1967) and is known as the *gap effect* (Dorris & Munoz, 1995; Fischer & Ramsperger, 1984; Kalesnykas & Hallett, 1987; Kingstone & Klein, 1993; Reuter-Lorenz, Hughes, & Fendrich, 1991).

With regard to the gap effect, saccadic reaction times (SRTs) appear to be more affected by the disappearance of a fixated object rather than by any physical changes of the fixated object. It has been shown that temporal cues predicting the target onset could facilitate saccadic reaction to the target due to the *general warning effect* (Kingstone & Klein, 1993; Reuter-Lorenz, Hughes, & Fendrich, 1991; Ross & Ross, 1980, 1981). The general warning effect has been observed with various types of transient signals, such as changes in color, luminance, and size of the fixation stimulus (Jin & Reeves, 2009; Pratt, Bekkering, & Leung, 2000), as well as acoustic signals (Pratt, Bekkering, & Leung, 2000). However, the removal of a visual fixation stimulus is still the most effective means of expediting the saccadic response (Jin & Reeves, 2009; Pratt, Bekkering, & Leung, 2000). For this reason, the disappearance of a fixated object might have a special influence on the initiation of subsequent action.

While the mechanism underlying the gap effect is still under debate (Jin & Reeves, 2009; Kingstone & Klein, 1993; Pratt, Lajonchere, & Abrams, 2006), there are two predominant theories: the *fixation–offset effect*, which is specific to the oculomotor system, and *disengagement of attention*. It has been demonstrated that removal of visual input to the oculomotor fixation region prior to target onset facilitates an oculomotor release from the active fixation process occurs in the superior colliculus (Munoz & Wurtz, 1992). This results in a quicker saccadic reaction to a subsequently presented target; otherwise, the release process will take place only after the appearance of the target (Fendrich, Hughes, & Reuter-Lorenz, 1991; Kingstone & Klein, 1993; Munoz & Wurtz, 1992; Reuter-Lorenz, Hughes, & Fendrich, 1991). Alternatively, it has also been suggested that the reduction in SRT may be attributed to higher mechanisms, such as attentional disengagement. This hypothesis was based on Posner's theory of attention, which states that attention has to be disengaged from one location before shifting

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to another (Posner, 1980). Thus, the removal of a fixation stimulus triggers this disengagement process, which in turn facilitates an immediate saccadic response following target onset (Fischer & Breitmeyer, 1987; Fischer & Weber, 1993; Mackeben & Nakayama, 1993; Pratt, Bekkering, & Leung, 2000; Pratt, Lajonchere, & Abrams, 2006). Although the neural mechanisms underlying the fixation offset effect and attentional disengagement may be different, both explanations assume that facilitation of the saccadic response is attributed to the removal of the fixated/attended prior to target presentation. In other words, as long as a fixated/attended visual object is present, the eyes tend to remain fixated.

While previous gap-effect studies have focused on the disappearance of the physical signal on the retina (e.g., Fendrich, Hughes, & Reuter-Lorenz, 1991; Kingstone & Klein, 1993; Pratt, Lajonchere, & Abrams, 2006; Reuter-Lorenz, Hughes, & Fendrich, 1991), the disappearance of a retinal signal does not always correspond to phenomenal/subjective disappearance. For instance, the retinal image of a moving object is often occluded, whereas its phenomenal permanence, which refers to the experience of the spatiotemporal continuity of an object even when their physical inputs are not available, is retained, along with expectation of its re-emergence (Burke, 1952; Gibson et al., 1969; Michotte, 1950). In the present study, we investigated whether the top-down components, especially phenomenal maintenance and expectation of a fixation stimulus reappearing, influences the saccadic gap effect, in addition to stimulus driven bottom-up components, such as the physical disappearance/maintenance of a fixation stimulus.

2. Experiment 1

In Experiment 1, we used the gradual occlusion technique to investigate whether the phenomenal permanence of a fixation stimulus influenced the gap effect. More specifically, we examined the difference in saccadic reactions following the removal of a fixation stimulus with and without occlusion.

2.1. Methods

2.1.1. Participants

Ten paid volunteers (age: 19–25 years; 6 women) participated in the experiment. All had normal oculomotor function and normal or corrected-to-normal vision. All participants gave written informed consent prior to the experiment.

2.1.2. Apparatus and stimuli

Participants were seated in a darkened room with their head stabilized on a chin-rest. Visual stimuli, generated using the MATLAB™ Psychophysics and Eyelink Toolbox extensions (Brainard, 1997; Cornelissen, Peters, & Palmer, 2002; Pelli, 1997), were displayed on a 21-inch CRT monitor (100 Hz, a viewing distance of approximately 56 cm) with a gray background (12.0° × 9.0°, 32.4 cd/m^2). The visual stimuli consisted of a white fixation dot (43.0 cd/m^2, 0.32° in diameter), a white target dot (same as the fixation stimulus), and black rectangular plates (i.e., occluders: 21.6 cd/m^2, 3.2° × 1.6°; Fig. 1). The fixation stimulus was presented

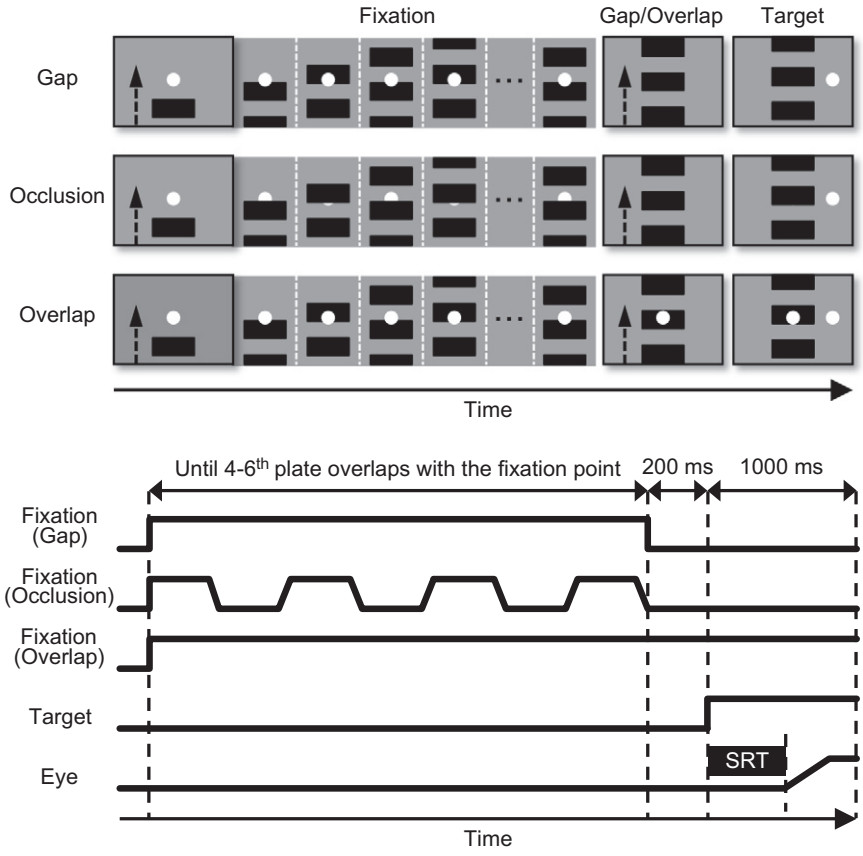

Fig. 1. Experimental stimuli (top) and timeline (bottom). Each trial started with the presentation of the fixation stimulus while the moving plates were passing behind (gap and overlap) or over (occlusion) the fixation stimulus. A fixation period lasted until 4–6 plates had completely overlapped the fixation stimulus. Following the fixation period, the fixation stimulus disappeared during the gap condition, was hidden during the occlusion condition, or remained in front of the plate during the overlap condition. Then, 200 ms later, the moving plates were stopped and the target was presented at either the left or right side of the fixation location. In Experiment 2, the color of the rectangular plates was identical to that of the background, while the other stimuli and procedures remained the same as Experiment 1. Saccadic reaction time (SRT) was defined as the time elapsed from the target onset to a saccade onset.