

On the limited role of target onset in the gap task: Support for the motor-preparation hypothesis

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Saccade latency is reduced when the fixation stimulus is removed shortly before a saccade target appears (gap task) as compared to when the fixation stimulus remains present (overlap task). To test the assumption that this gap effect benefits from advanced motor preparation (M. Paré & D. P. Munoz, 1996), we manipulated target onset independently of the signal to launch a saccade (peripheral offset at the mirror location). In [Experiment 1](#), we showed that, when the target appears at one of only two possible locations, target onset strongly improves performance (lower latency, higher accuracy) in the overlap task but not in the gap task. In [Experiment 2](#), we found that the lack of an effect of target onset in the gap task was not due to inhibition of a reflexive response to the transient associated with the offset (go signal) in our task. In [Experiment 3](#), we manipulated target onset and target uncertainty (two, four, or eight potential target locations) in gap and overlap tasks. As target uncertainty increased, the gap effect decreased, and the effect of target onset on saccade latency in the gap condition became greater. Overall, our results suggest, in line with the motor-preparation hypothesis, that saccade metrics in a gap task are computed before the target is actually displayed and that advanced motor preparation is enhanced when the location of the target is predictable. Analyses of anticipations and regular-latency errors corroborated this view.

Keywords: saccade latency, saccade accuracy, gap effect, target onset, target uncertainty, saccade generation

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Introduction

The gap effect is a very robust phenomenon, which was discovered by Saslow (1967). It shows that executing a saccadic eye movement from a fixated stimulus to an appearing target in the periphery is strongly facilitated if the fixated stimulus is removed shortly before the new stimulus actually appears. Facilitation is reflected in shorter saccade latencies in the gap condition as compared to the overlap condition, where the fixation stimulus remains present during saccade target presentation. As shown by Fischer and Boch (1983) and Fischer and Ramsperger (1984), the gap task may produce bimodal saccade-latency distributions, with express saccades (latencies of 80 to 130 ms) and regular saccades (latencies of 150 to 250 ms) forming the two modes. However, saccade latencies are strongly reduced in the gap condition as compared to the overlap condition even when no express saccades are observed (e.g., Kingstone & Klein, 1993; Paré & Munoz, 1996; Reuter-Lorenz, Hughes, & Fendrich, 1991; Wenban-Smith & Findlay, 1991). Therefore, we refer to the gap effect as a general reduction in saccadic reaction time.

The aim of our research was to investigate whether target onset contributes to the gap effect. As revealed in previous studies, target onset is not needed to induce a strong gap effect; when the go signal for the saccade is either a tone (Abrams, Oonk, & Pratt, 1998) or a verbal

instruction (Forbes & Klein, 1996), saccade latency still differs between gap and overlap conditions and, thus, even in the absence of target onset. Our goal was not to challenge these findings but rather to compare the influence of target onset in the gap and overlap tasks, as this may be critical to understanding the processes involved in saccade generation.

Two components are generally considered to generate the gap effect, one that relates to activity in the fixation system and one that arises from an offset-related warning signal indicating that a saccade will soon be required. There is agreement on the first component, although the hypothesis was formulated in several ways by different authors (e.g., Dorris & Munoz, 1995; Findlay & Walker, 1999; Fischer & Weber, 1993; Kingstone & Klein, 1993; Mayfrank, Mobashery, Kimmig, & Fischer, 1986; Pratt, Bekkering, & Leung, 2000; Tam & Stelmach, 1993). The basic assumption is that stimulus offset expedites fixational disengagement, which, in turn, facilitates the generation of a saccade as compared to a situation where fixation is sustained by an enduring fixation stimulus.

For the second, warning-type component, two fundamentally different views were proposed. In their model of saccade generation, Findlay and Walker (1999) attributed the warning-signal effect to high-level descending influences in the WHEN pathway. They assumed that fixation offset places the oculomotor system in a state of readiness. A saccade target is expected to appear at a certain point in time, which allows the system to be temporally prepared

and to generate a quicker response to target onset (see also Ross & Ross, 1980). In other words, activity of the fixation system is reduced at the appropriate time, which facilitates saccade triggering as compared to when the fixation system is still engaged at the saccade go signal as in an overlap condition. The temporal-preparation assumption was derived from studies showing that temporally informative stimuli (visual or nonvisual) greatly reduce response latencies in an overlap condition and, thus, even in the absence of fixation offset (Pratt, Bekkering, & Leung, 2000; Reuter-Lorenz, Oonk, Barnes, & Hughes, 1995; Ross & Ross, 1980; Ross & Ross, 1981; Tam & Stelmach, 1993).

In contrast to the Findlay and Walker model, several authors attributed readiness to activity in the WHERE pathway (Becker, 1989; Dorris & Munoz, 1998, 1999; Dorris, Paré, & Munoz, 1997; Godijn & Theeuwes, 2002; Kowler, 1990; Munoz, Dorris, Paré, & Everling, 2000; Munoz & Fecteau, 2002; Paré & Munoz, 1996; Trappenberg, Dorris, Munoz, & Klein, 2001; West & Harris, 1993; see also Vitu, 1993). This alternative is referred to as the motor-preparation hypothesis and assumes that an oculomotor program coding the metrics of a saccade can be at least partially prepared before the target comes on or the signal to launch a saccade is given. The hypothesis was inspired by the fact that express-saccade occurrence and saccadic latencies in general are strongly modulated by the spatial predictability of the target stimulus (Dorris & Munoz, 1998; Kingstone & Klein, 1993; Paré & Munoz, 1996). In addition, the occurrence of express saccades often requires extensive training, and these training effects were shown to be spatially selective. Once trained to specific target locations, monkeys made express saccades only to targets at or close to the trained location. In addition, the latency of regular saccades was lowest at the trained location while a (reduced) gap effect was present for each of the other tested locations (Paré & Munoz, 1996; see also Boch & Fischer, 1986; Fischer, Boch, & Ramsperger, 1984).

Temporal- and motor-preparation hypotheses give rise to different predictions for the role of target onset in the gap task. The latter, or the assumption that readiness is

localized, leads to the prediction that target onset should have minimal impact when it occurs after a motor program is ready to go. Thus, neither saccade latency nor saccade accuracy should be affected by target onset when the saccade target appears at a predictable location, and the gap duration is long enough for the motor program to be completed in advance (i.e., about 200 ms; Dorris et al., 1997; see also Munoz et al., 2000). However, as the number of potential target locations increases and advance motor programming becomes less likely, the effect of target onset should become progressively greater, approaching the effect expected in an overlap task.

Alternatively, if readiness is not attached to a particular location as assumed in Findlay and Walker's (1999) temporal-preparation hypothesis, the effect of target onset should be unrelated to the predictability of target location. Rather, this should depend on the predictability of the gap duration or on any variable that increases the chance that the fixation system is disengaged when the signal for a saccade occurs. If the level of activity in the fixation system is near a lower-bound threshold when a saccade is called for, the eyes should be launched at about the same time whether or not a stimulus appears in peripheral vision. Thus, target onset should have minimal influence on saccade latency when the gap duration is constant or when expectations on when the eyes should move can reduce the level of fixation activity at the appropriate time. In contrast, if the peripheral onset occurs while the fixation system is still engaged, it should modify the fixate–move equilibrium and reduce saccade latency. Note that, independently of whether or not the fixation system is disengaged at the expected time for a saccade, target onset may affect saccade accuracy. Indeed, in Findlay and Walker's model, the metrics of a saccade are determined in relation with the point of maximum salience. This may be more clearly defined if a visual event (i.e., an onset) occurs at the target location.

Our series of experiments was aimed at distinguishing between temporal- and motor-preparation accounts for the gap effect based on behavioral data in human subjects. Because, in traditional gap and overlap conditions, target

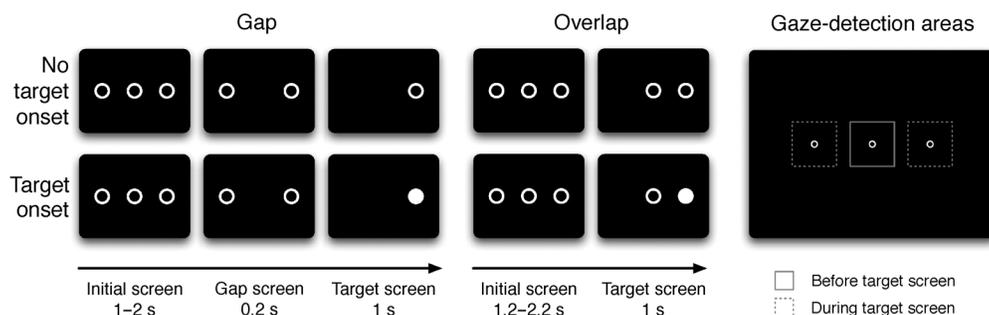


Figure 1. Sequences of visual stimulation in the four experimental conditions (modified gap and overlap tasks) in Experiment 1. Stimulus proportions are illustrated in the panel to the right; the areas surrounded by gray lines were used for online control of fixation (solid line) and response detection (dashed line). The target location to the right was used for illustrative purposes.

onset is the go signal for a saccade, modified versions of the gap and overlap tasks were introduced. Participants were instructed to generate a saccade as soon as one of several (two or more) previously displayed peripheral landmarks disappeared (see, e.g., Figure 1). The saccade target corresponded to the landmark at the mirror location of the peripheral offset. It lighted up in the target-onset conditions, but it did not change in the no-target-onset conditions. Experiment 1 exhibited a strong influence of peripheral target onset on saccade latency and saccade accuracy in the overlap task but not in the gap task. These results could not be explained by response suppression to the offset transient used in our task (see Experiment 2). Experiment 3 showed that the effect of target onset in the gap task depends on the predictability of target location, as predicted in the motor-preparation hypothesis.

Experiment 1: Different role of target onset in the gap and overlap tasks

Experiment 1 aimed at distinguishing between temporal- and motor-preparation assumptions by using conditions that presumably favored motor preparation. The target stimulus appeared at a constant eccentricity (4°), left or right of the fixation stimulus, and the gap duration was maintained at 200 ms. This interval has been shown to produce clearer gap effects and to favor the occurrence of express saccades (Bell, Everling, & Munoz, 2000; Braun & Breitmeyer, 1988; Dorris & Munoz, 1995; Krauzlis & Miles, 1996; Mayfrank et al., 1986; Opris, Barborica, & Ferrera, 2001; Paré & Munoz, 1996; Saslow, 1967; Tanaka & Shimojo, 2001). Moreover, physiological studies suggested that saccade preparation is highly advanced 200 ms into the gap period (Dorris et al., 1997; see also Munoz et al., 2000), hence predicting a reduced effect of target onset on latency and amplitude for this gap duration, at least under the motor-preparation hypothesis.

In contrast, in the framework of the temporal-preparation hypothesis, saccade accuracy was expected to improve with target onset, and this in both gap and overlap tasks. Furthermore, an effect of target onset on saccade latency was expected not only in the overlap but also, to some extent, in the gap condition, at least under the additional assumption that activity of the fixation system was reinforced in the modified gap paradigm. The conditions used, that is, the simultaneous presence of two peripheral landmarks from the beginning of a trial until the end of the gap period, may favor an increase in saccade latency (e.g., the remote distractor effect; Lévy-Schoen, 1969; Walker, Deubel, Schneider, & Findlay, 1997; Walker, Kentridge, & Findlay, 1995). Because the remote distractor effect and more generally prolonged

saccade latencies are assumed to reflect enhanced activity of the fixation system (see Findlay and Walker, 1999), the conditions should be met for target onset to reduce saccade latency even in a gap condition. In addition, the gap effect in the modified gap paradigm should be reduced compared to that obtained when there is no visual stimulation during the gap period (as in the control condition), and fixation disengagement at the saccade go signal is more likely.

Methods

Participants

Twenty university students (18 women, 2 men) were paid 7€ or received study credit for their participation. They were 19 to 31 years old (22 years on average), had normal or corrected-to-normal vision, and were in good health. This and the following experiments were performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki, and individuals gave their informed consent prior to their participation in the study.

Experimental setup and eye-movement recordings

Participants were seated in a silent and dimly lit room with their heads stabilized by a chin rest, 50 cm in front of a computer screen. Stimuli were presented on a 22-in. iiyama HM204DT CRT ($1,024 \times 768$ resolution or $46^\circ \times 34^\circ$ of visual angle; refresh rate, 100 Hz). The experiment was controlled by an Apple Power Macintosh G4 computer. Eye-position data were recorded and available online using an EyeLink-II head-mounted system (SR Research, Osgoode, Ontario, Canada) with a sampling rate of 500 Hz and a noise-limited spatial resolution better than 0.01° . Automatic head-movement correction was applied. The experimental software that controlled stimulus display and response collection was implemented in MATLAB (MathWorks, Natick, MA, USA), using the Psychophysics (Brainard, 1997; Pelli, 1997) and EyeLink (Cornelissen, Peters, & Palmer, 2002) toolboxes.

Modified gap task and procedure

Participants performed 8 practice trials and 240 test trials of a simple saccade task, which consisted of modified versions of the classical gap and overlap tasks. This experimental block was followed by a control block of 8 practice trials and 60 test trials where classical gap and overlap conditions were tested. Practice trials were comparable to test trials in all respects.

In the experimental block, three horizontally aligned white rings (diameters subtending 0.4° of visual angle; luminance of white was 53.1 cd/m^2) were displayed centrally on a black background (luminance $< 0.1 \text{ cd/m}^2$); they were separated by a visual angle of 4° . Participants fixated the central ring. After an initial fixation period of

1.2 to 2.2 s, one of the peripheral rings was removed (go signal) and subjects were required to quickly initiate a saccade to the remaining eccentric target. A 2×2 design was defined, with fixation offset (gap vs. overlap) and target onset (onset vs. no onset) as independent variables. This resulted in four experimental conditions, referred to as gap target onset, overlap target onset, gap no target onset, and overlap no target onset.

Figure 1 displays the sequence of events in these conditions. In the gap conditions, the central ring was extinguished for the final 200 ms of the initial fixation period; in the overlap conditions, the central ring remained on the screen over the whole trial. In the onset conditions, the saccade target switched to a filled, white circle simultaneously with the peripheral offset at the mirror location. In the no-target-onset conditions, peripheral offset was accompanied by no visual change at its mirror position (the actual target location). Saccadic responses (eye-position shift to either of the two targets) were detected online and terminated the trial if eye position remained for more than 200 ms in an area of $3^\circ \times 3^\circ$ centered on one of the two target locations. To enable blinking, we introduced intertrial intervals of 1 s with no visual stimulation before starting the next trial. There were 60 trials in each of the four experimental conditions (30 left and 30 right targets); these were presented in a random order within the same block of 240 trials.

In the control block, the same spatiotemporal layout of the task was used, except that each trial started only with the presentation of a central ring. In both conditions, the go signal was given by target onset (a filled, white circle presented to the right or to the left of the initial fixation stimulus). There were a total of 30 trials in each condition; in half of the trials, the target appeared to the left of fixation, and in the other half, it appeared to the right of fixation. Gap and overlap trials were randomly mixed in a single block. The control block was always run after the experimental block to facilitate execution of the modified gap task.

In both blocks of trials, a trial was aborted if the participant's gaze moved out of a $3^\circ \times 3^\circ$ region centered on the fixation stimulus before the go signal or if no response was detected within the 1 s after the go signal (see right panel of Figure 1). Aborted trials were recycled and repeated in a random order after the 240 regular trials (or 60 trials in the control block). The eye tracker was calibrated (standard 9-point grid) at the beginning of each block of trials and every 30 trials in each block. Every 10th trial, a drift correction was carried out. Before each trial, a fixation spot was displayed at the center of the computer screen. To start a trial, fixation had to be detected in a $3^\circ \times 3^\circ$ region centered at the fixation spot for 200 ms. Otherwise, a drift correction was carried out and the trial was restarted. If the eyes were still not detected within the critical area, the calibration was repeated.

Data analysis

For data analysis, post hoc saccade detection was performed using an improved version (Engbert, 2006) of the algorithm developed by Engbert and Kliegl (2003). Velocities were computed from subsequent samples in the series of eye positions in a response time window of 1 s from the go signal (peripheral offset and target onset in experimental and control conditions, respectively). Saccades were detected in 2-D velocity space using thresholds for peak velocity ($6 SD$) and minimum duration (8 ms, or four data samples). The first saccade that shifted the gaze to the center of a target location $\pm 1.5^\circ$ was considered the response saccade. Saccade latency was defined as the latency between the go signal (offset of one of the two peripheral landmarks) and saccade onset. Trials including saccades larger than 1° of visual angle prior to the response saccade were discarded. For all analyses (except Figure 3), trials with response latencies shorter than 100 ms¹ and response saccades going in the wrong direction were excluded. Some trials had to be excluded due to data loss during eye-movement recording. Altogether, the 20 participants contributed a total of 3,942 experimental trials (out of 4,800 or 82.1%) and 1,128 control trials (out of 1,200 or 94.0%) surviving the above rejection criteria.

Where provided, confidence intervals were computed using a simple bootstrapping technique (Efron & Tibshirani, 1993): From an original sample of N values, 1,000 bootstrap samples were generated, each by selecting (with replacement) N values of the original sample. We computed 1.96-fold of the standard deviation of the means of these 1,000 bootstrap samples to generate 95% confidence intervals of the mean of the original sample. To allow for within-subject comparisons, we removed between-subject variance beforehand, using the procedure proposed by Cousineau (2005).

Results

Figure 2A presents mean saccade latencies (and confidence intervals) in the different conditions. First, a gap effect was observed in the control conditions: On average, saccade latency was 77 ms (33%) shorter in the gap condition as compared to the overlap condition as confirmed by a t test for paired samples, $t(19) = 10.89$, $p < .001$. Second, a strong gap effect was observed in the experimental target-onset and no-target-onset conditions. The reduction in saccade latency in the gap condition as compared to the overlap condition was 123 ms (34%) on average in the no-target-onset condition and 100 ms (30%) on average in the target-onset condition. Moreover, when target onset accompanied the go signal (peripheral offset), it decreased saccade latencies by 28 ms in the overlap condition, while there was a 5-ms difference in the gap condition. A 2×2 repeated measures ANOVA

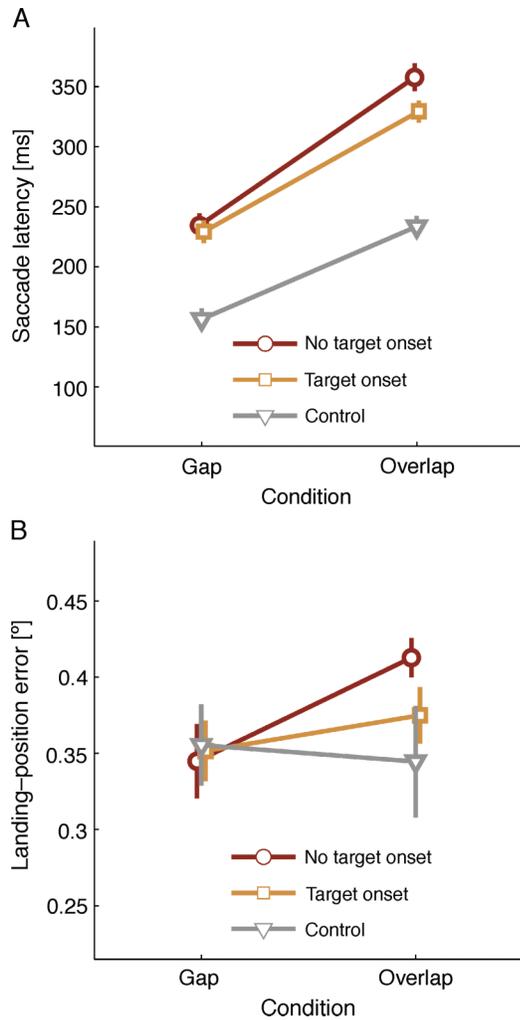


Figure 2. Saccadic performance in the experimental and control conditions of [Experiment 1](#). (A) Mean saccade latency (the delay between peripheral offset and saccade onset). (B) Mean saccade accuracy (absolute distance between target and saccade endpoint). Error bars are 95% confidence intervals.

revealed main effects of fixation offset, $F(1, 19) = 229.58$, $p < .001$, and target onset, $F(1, 19) = 29.62$, $p < .001$. [Figure 2A](#) suggests that the latter effect was only due to a difference in saccade latencies between the two overlap conditions, resulting in a significant interaction between fixation offset and target onset, $F(1, 19) = 10.19$, $p = .0048$. This was also borne out by post hoc comparisons, showing a significant effect of target onset in the overlap condition, $t(19) = 5.17$, $p < .001$, but not in the gap condition, $t(19) = 1.36$, $p = .19$. In addition, saccade latency was clearly longer in the experimental conditions as compared to the control conditions, and the gap effect was greater in the experimental conditions. There was actually a significant interaction between fixation offset and version of task (target onset vs. control) in a repeated measures ANOVA,

$F(1, 19) = 9.72$, $p = .0057$, which, however, was not reflected in the relative gap effects in these two conditions (30% vs. 33%).

[Figure 3](#) displays the distributions of saccade latency in the four experimental and the two control conditions; here, all saccades, including the saccades launched within 100 ms and saccades going in the wrong direction, were considered. Distributions were computed as the average of individual saccade-latency distributions; saccade latencies were binned into 10-ms time intervals. Correct responses were plotted upward, whereas directional errors, that is, saccade responses landing on the side contralateral to the target, were plotted downward. A number of results can be gathered from this figure: First, none of the distributions display a separate express-saccade peak. Second, the distributions in the two experimental gap conditions are extremely similar, showing two maxima, one at very short saccade latencies (80 ms) and one at regular saccade latency (220 ms). In addition, directional errors occurred only at the short-latency peak and about as often as correct short-latency responses, suggesting that the first peak of the distribution represents anticipatory saccades. The proportion of correct and incorrect anticipatory responses was about the same in target-onset ($12.1\% \pm 1.5\%$ vs. $12.9\% \pm 1.8\%$) and no-target-onset conditions ($13.4\% \pm 1.5\%$ vs. $13.9\% \pm 1.4\%$). The distributions of saccade latencies in the overlap conditions differed only in the location of their peak but not in the number of peaks. In particular, no anticipations and directional errors were observed in these conditions. The occurrence of anticipations and directional errors was clearly unique to the experimental gap conditions (see [Figure 3](#)). Finally, saccade-latency distributions associated with control gap and overlap conditions were shifted toward shorter latencies in comparison to the experimental conditions. Neither of them was bimodal nor did these conditions exhibit directional errors.

To examine whether the manipulated variables affected saccade metrics, we computed saccade accuracy as the absolute distance between a target and the saccade's endpoint. We plotted mean saccade accuracy (and confidence intervals) for the four experimental and the two control conditions in [Figure 2B](#). We can derive from this figure that saccade accuracy was comparable across the gap conditions. However, in the overlap task, accuracy was enhanced in the target-onset condition as compared to the no-target-onset condition. This result was confirmed by statistical analyses. A repeated measures ANOVA with fixation offset (gap vs. overlap) and target onset (yes vs. no) as independent variables yielded a main effect of condition, $F(1, 19) = 14.57$, $p = .0012$, no main effect of target onset, $F(1, 19) = 1.58$, $p = .22$, and a reliable interaction, $F(1, 19) = 5.58$, $p = .029$. A post hoc contrast revealed a reliable difference between no-target-onset and target-onset conditions for overlap trials, $t(19) = 2.90$, $p = .0093$, but not for gap trials, $t(19) = 0.38$, $p = .71$.

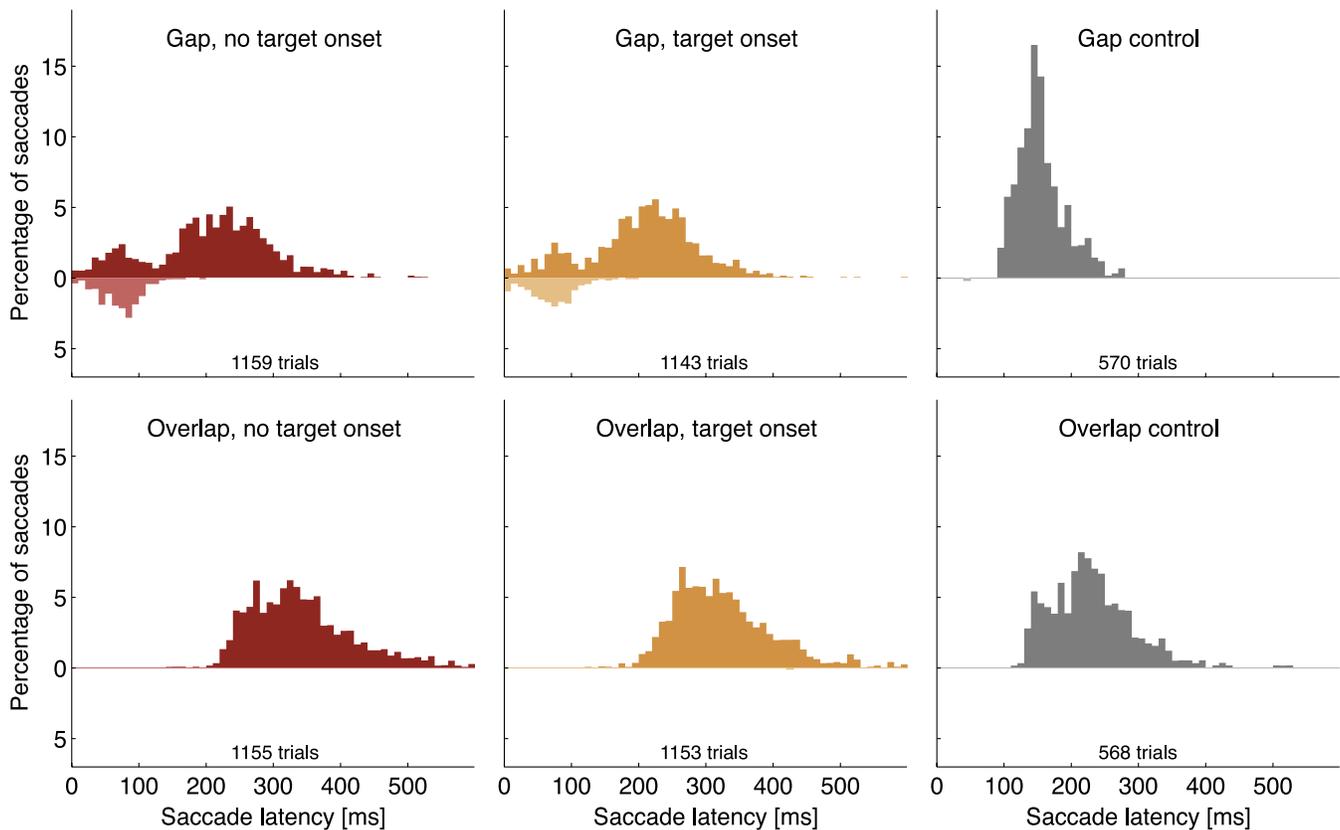


Figure 3. Distributions of saccade latencies for correctly (dark, upward) and incorrectly (light, downward) directed saccade responses in the four experimental and the two control conditions of [Experiment 1](#). Binning was set to 10 ms.

Discussion

This experiment did not provide evidence for an effect of target onset in a gap task; neither saccade latency nor saccade accuracy differed when the go signal for the saccade (a peripheral offset) was accompanied by a luminance change at the (mirror) target location. In contrast, target onset had some impact on eye behavior in the overlap task because saccade latency was reduced and saccade accuracy was increased in the target-onset condition as compared to the no-target-onset condition. The data are consistent with the motor-preparation hypothesis (Paré & Munoz, 1996). They suggest that, under specific conditions, that is, if a gap of 200 ms precedes the go signal for the saccade and the uncertainty of target location is reduced (4° left or right of fixation, highlighted by landmarks), saccade metrics are computed in advance. This can be achieved through guessing strategies and a single motor program associated with the expected target direction on a given trial. Alternatively, this precomputation may arise from two motor programs (associated with the two possible target locations) being initiated following fixation offset but only one program being launched following the go signal. The program(s) may require something like 200 ms to be achieved (e.g., Dorris et al., 1997), but in some instances,

programming may take less time or it may be initiated earlier, accounting therefore for the occurrence of anticipatory responses in the experimental gap but not in the overlap condition.

As suggested in several prior studies, temporal preparation may also contribute to the gap effect (e.g., Ross & Ross, 1980; Ross & Ross, 1981). However, it seems quite unlikely that this was responsible for the gap effect observed in this experiment. First, there was no effect of target onset on saccade accuracy in the gap condition. Note that this cannot be attributed to the luminance change being too small or the number of lighted pixels in the target-onset condition being too low because the same manipulation proved to be successful in the overlap condition; it remains undetermined, however, whether the effect in the overlap condition was due to the onset itself or to the greater number of lighted pixels in the target-onset condition. Second, despite an overall increase of saccade latency in the modified gap paradigm and, hence, despite the fact that the fixation system was probably not completely disengaged at the saccade go signal, target onset failed to affect saccade latency in the gap condition. Third, anticipations were much more frequent in the experimental gap than in the other conditions. These findings suggest, contrary to the temporal-preparation hypothesis, that saccade metrics

were computed quite often before the go signal for the saccade.

It remains undetermined at this stage as to why saccade latency was overall longer in the experimental gap and overlap conditions compared to the control conditions. As noted above, the fact that two peripheral landmarks were simultaneously displayed, and remained present, until the end of the gap period could be responsible for the overall increase of saccade latency. An alternative is that the overall increase of saccade latency in the experimental conditions resulted from the task itself, which closely resembled an antisaccade task (Hallett, 1978). Because the go signal for the saccade was a peripheral offset at the target mirror location, it may well be that the transient associated with the offset captured the eyes and that prolonged saccade latencies resulted from participants trying to inhibit reflexive responses to the visual event. In such conditions, target onset was a minor visual event, and the chance that it influenced saccade latency was reduced. If this proved to be the case, then it would suggest that [Experiment 1](#) was only a weak test of temporal- and motor-preparation hypotheses. [Experiment 2](#) followed up on this objection.

Experiment 2: Is the modified gap/overlap paradigm an antisaccade task?

The purpose of [Experiment 2](#) was to test the antisaccade account of the findings of [Experiment 1](#), that is, whether the overall increase of saccade latency in the modified gap paradigm resulted from inhibition of reflexive responses toward the peripheral offset. Participants performed two blocks of trials. One block replicated the four experimen-

tal conditions of [Experiment 1](#), that is, target onset and no target onset in gap and overlap tasks. In that block, three stimuli were initially displayed (a central fixation stimulus and two peripheral landmarks). The offset of one of the peripheral stimuli was the signal to generate a saccade toward the target at the mirror location. We will refer to this block as the “offset-go” block. In another block of trials (“onset-go” block), three versions of gap and overlap conditions were presented; these were referred to as the stimulus-offset, stimulus-static, and stimulus-absent conditions (see [Figure 4](#)). In all three conditions, the signal to launch a saccade corresponded to the onset of the target, but in both stimulus-static and stimulus-offset conditions, the initial display was the same as in the experimental block (a central stimulus and two peripheral landmarks) and target onset resulted from a change in luminance at the target location. In the stimulus-offset condition, target onset occurred simultaneously with the offset of the landmark at the mirror location, whereas in the stimulus-static condition, target onset was not accompanied by a peripheral offset; instead, two peripheral stimuli were presented throughout the trial. The remaining stimulus-absent condition was identical to the control condition of [Experiment 1](#); it implemented classical gap and overlap tasks, with a single foveal stimulus at the beginning of the trial.

According to the antisaccade hypothesis, saccade latency should be prolonged in the stimulus-static and the stimulus-offset conditions as compared to the stimulus-absent condition, and it should be longer in the stimulus-offset than in the stimulus-static condition. In contrast, if the lengthening of saccade latency in the modified gap paradigm came from the bilateral presentation of two potential targets at the beginning of a trial, then saccade latency should not vary between stimulus-static and stimulus-offset conditions. Furthermore, if an effect was to be observed, it should be in the opposite direction, with stimulus offset being facilitating.

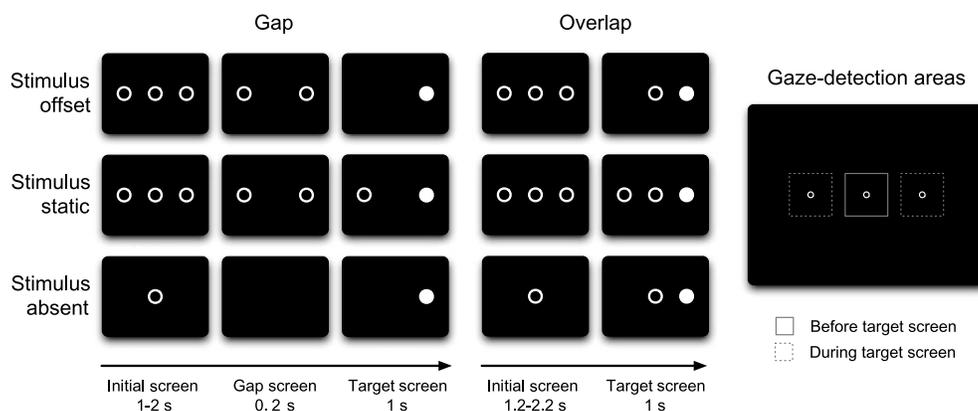


Figure 4. Sequences of visual stimulation in the six conditions of the onset-go block in [Experiment 2](#). Stimulus proportions are illustrated in the panel to the right; the areas surrounded by gray lines were used for online control of fixation (solid line) and response detection (dashed line). The target location to the right was used for illustrative purposes.

Methods

Participants

Twenty-five university students (22 women, 3 men) were paid 7€ or received study credit for their participation. They were 19 to 29 years old (22 years on average), had normal or corrected-to-normal vision, and were in good health.

Experimental setup and eye-movement recordings

Experiment 2 was run using the same experimental setup and equipment as in **Experiment 1**.

Task and procedure

A session consisted of two experimental blocks; their order was counterbalanced across subjects. In the offset-go block, we replicated the experimental conditions of **Experiment 1**, that is, a 2×2 repeated measures design with fixation offset and target onset as independent variables. The task and the procedure in this block were identical to those in **Experiment 1**, except that, this time, a participant performed only 36 trials per condition; aborted trials were recycled at the end of the block.

In the onset-go block, there were a total of six conditions that resulted from the combination of fixation offset (gap vs. overlap) with peripheral-stimulus type (offset, static, and absent). The 36 trials of each of the six conditions were presented in a random order; recycled trials were added at the end of the block. All other aspects of the onset-go block were the same as in **Experiment 1**. In one half of the trials, the target was displayed to the left of fixation, and in the other half, it was displayed to the right (balanced for each condition).

Data analysis

Response-saccade detection was based on the same criteria as in **Experiment 1**, as were the criteria for trial exclusion. One participant had to be excluded because of a misunderstanding of the task (she always waited for the offset of the fixation stimulus in the offset-go block and, thus, had nearly no correct trials in the overlap conditions). Furthermore, four subjects had very few valid trials (less than 25% in at least one condition) and were therefore excluded. Altogether, the remaining 20 participants contributed a total of 2,346 offset-go trials (out of 2,880 or 81.5%) and 3,794 onset-go trials (out of 4,320 or 87.8%) surviving the rejection criteria.

Results and discussion

Offset-go blocks: Replicating Experiment 1

The upper panel of **Figure 5A** shows mean saccade latencies (and confidence intervals) in the offset-go blocks. We first computed planned contrasts, testing the

effect of target onset in the gap and overlap conditions of that block. In the overlap condition, target onset reduced response latencies by 52 ms on average, $t(19) = 3.56$, $p = .0021$. A numerically smaller reduction of response latencies in the gap task (23 ms on average), however, was also reliable, $t(19) = 3.16$, $p = .0051$. To determine whether the effect of target onset was smaller in the gap than in the overlap condition, we conducted a repeated measures ANOVA with target onset and condition as independent variables. Indeed, the interaction between these two factors was reliable, $F(1, 19) = 4.91$, $p = .039$. Moreover, there was a strong gap effect, $F(1, 19) = 136.20$, $p < .001$, and a main effect of target onset, $F(1, 19) = 15.75$, $p < .001$.

Figure 5B shows saccade-latency distributions for the different conditions in the offset-go block. These were computed the same way as the ones presented in **Figure 3** (**Experiment 1**). Correct responses were plotted upward, whereas directional errors, that is, the saccades landing on the side contralateral to the target, were plotted downward. Most characteristics of the distributions that were reported for the experimental conditions of **Experiment 1** were also observed in the current experiment. In the gap conditions, the distributions consist of two modes; the first peak corresponds to saccades with an average latency of about 80 ms, and the second corresponds to saccades with regular latencies (between 130 and 400 ms). None of the distribution contains a separate express-saccade mode. Directional errors nearly exclusively occurred at the short-latency peak. Both correct and misdirected saccades were frequently observed, underpinning the idea that this share of the responses was anticipatory. The proportion of anticipatory responses was about the same in target-onset and no-target-onset conditions. As in **Experiment 1**, the distributions in the overlap conditions show a single peak shifted toward slower response times in the no-target-onset condition. No anticipations and directional errors were observed in these conditions.

Further analyses examined the influence of target onset on saccade accuracy in gap and overlap tasks of the offset-go block (see upper panel of **Figure 6**). Again, the data revealed no effect of target onset on saccade accuracy in the gap task, $t(19) = 1.08$, $p = .29$, but an effect in the overlap task, $t(19) = 4.08$, $p < .001$.

Thus, the offset-go data of **Experiment 2** nearly perfectly replicated the findings of **Experiment 1**. The only exception was a slight influence of target onset on saccade latency in the gap task. This finding is consistent with a temporal-preparation account of the gap effect. However, the fact that saccade accuracy did not vary with target onset in the gap task, in both **Experiment 1** and **Experiment 2**, suggests that, on some trials at least, saccade metrics were computed before the signal to launch a saccade to a particular location. This clearly contradicts the assumption that temporal preparation, but not motor preparation, contributes to the gap effect (see Findlay & Walker, 1999).

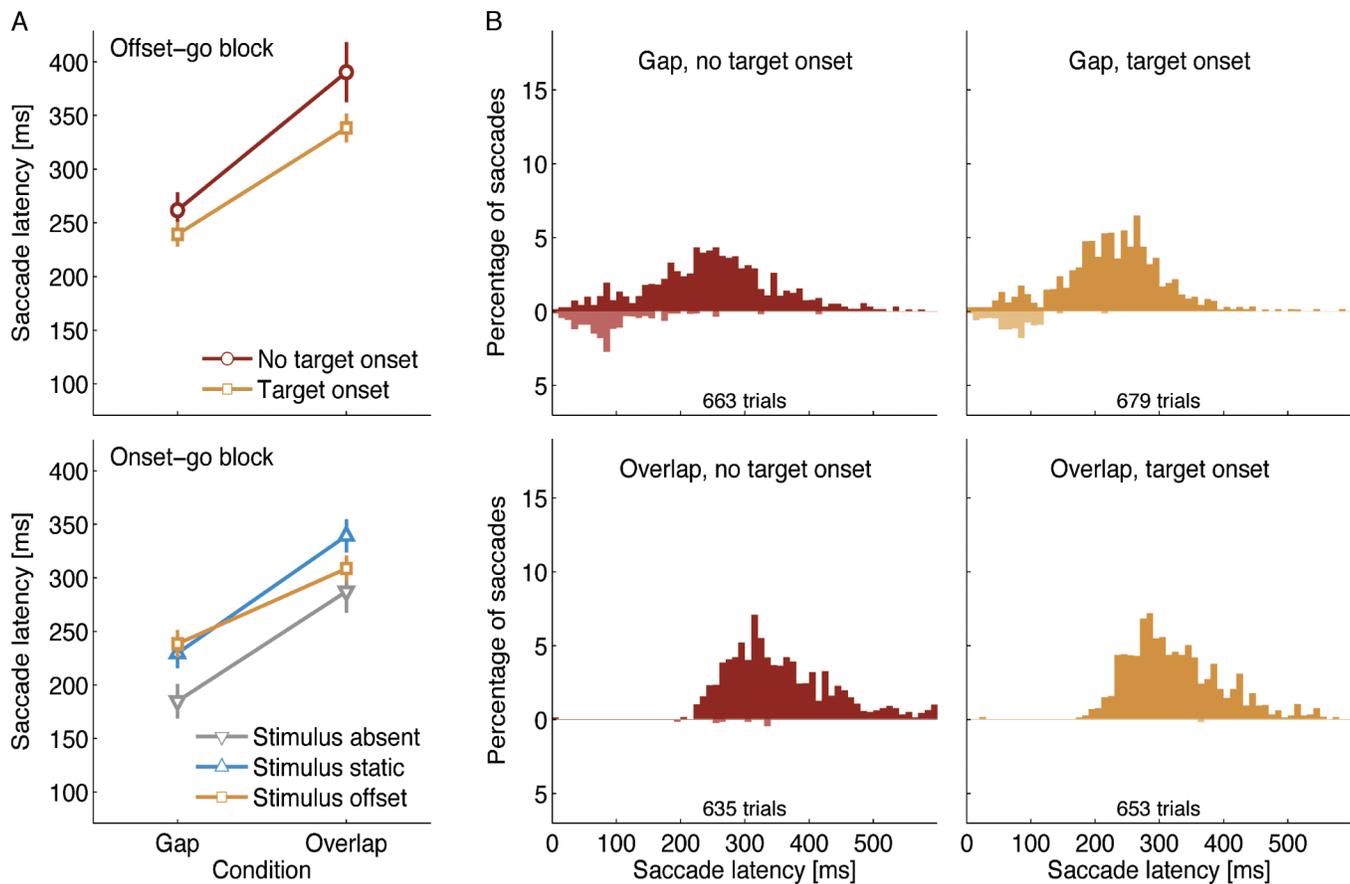


Figure 5. Saccade latencies in Experiment 2. (A) Mean saccade latencies for the different conditions of the onset-go block and the offset-go block. Error bars are 95% confidence intervals. (B) Distributions of saccade latencies for correctly (dark, upward) and incorrectly (light, downward) directed saccade responses in the four conditions of the offset-go block. Binning was set to 10 ms.

Onset-go blocks: Against an antisaccade account

A comparison of the data in the offset-go block and in the stimulus-absent condition (upper and lower panels of Figure 5A, respectively) shows, as in Experiment 1, that response times were largely increased in the modified gap paradigm. It is quite unlikely that the time cost resulted from the transient associated with the peripheral offset and the related saccade inhibition, as assumed under the antisaccade explanation. Indeed, as shown in the lower panel of Figure 5A, mean saccade latency tended to be shorter, and not longer, in the stimulus-offset than in the stimulus-static condition of the overlap task (31 ms), whereas it was only very slightly increased (9 ms) in the stimulus-offset condition of the gap task.

A repeated measures ANOVA with fixation offset and peripheral-stimulus type as independent variables revealed strong effects of fixation offset (gap effect), $F(1, 19) = 83.53$, $p < .001$, and peripheral-stimulus type, $F(2, 38) = 81.43$, $p < .001$. Moreover, the gap effect varied across different peripheral-stimulus types, $F(2, 38) = 7.61$, $p = .0017$. Post hoc analyses indicated that there was no interaction between fixation offset and peripheral-stimulus type for the contrast involving stimulus-static and stimulus-absent conditions, $F(1, 19) = 0.28$, $p = .61$, whereas there

was such an interaction for the contrast involving stimulus-static and stimulus-offset conditions, $F(1, 19) = 28.58$, $p < .001$. Saccade latencies were, on average, 11 ms shorter in the stimulus-offset than in the stimulus-static condition, $F(1, 19) = 11.95$, $p = .0026$; the 31-ms difference in the overlap task was significant, $t(19) = 5.38$, $p < .001$, as was the reverse 9-ms effect in the gap task, $t(19) = 2.32$, $p = .032$.² Note that saccade accuracy was comparable across the different conditions (see Figure 6). An omnibus test (repeated measures ANOVA), with fixation offset and peripheral-stimulus type as factors, yielded no significant effects; all F values < 1.82 , all p values $> .19$.

In summary, the transient associated with the peripheral offset did not produce major interference. It only very slightly increased saccade latency in the gap condition, and it greatly facilitated saccade programming in the overlap condition (see also Todd & Gelder, 1979). The peripheral offset, therefore, cannot account for the 50- to 80-ms overall increase of saccade latency in the modified gap paradigm of Experiments 1 and 2 and suggests that the inhibition of reflexive responses toward the peripheral offset was not responsible for our findings. In fact, as revealed by studies on oculomotor capture, transients

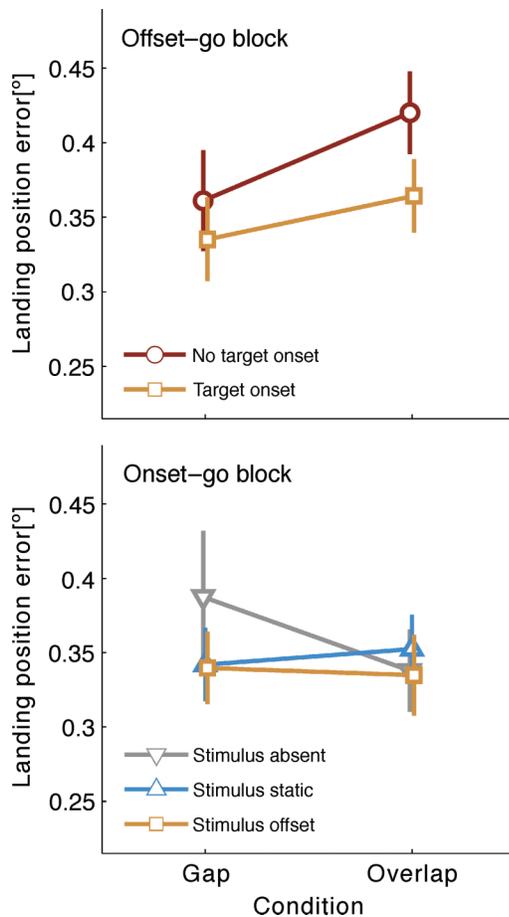


Figure 6. Mean saccade accuracy for the conditions of the offset-go block (upper panel) and the onset-go block (lower panel) in Experiment 2. Error bars are 95% confidence intervals.

associated with peripheral offsets rarely generate reflexive eye movements (e.g., Boot, Kramer, & Peterson, 2005). In addition, it must be noted that in both experiments, the saccades performed in the modified gap paradigm differed from responses in an antisaccade task. First, the gap effect was greater (in terms of absolute time) in the experimental conditions as compared to the control conditions, whereas the gap effect is usually much weaker for antisaccades than for prosaccades (Reuter-Lorenz et al., 1991, 1995). Second, in antisaccade tasks, participants often fail to inhibit visually driven responses and erroneously generate prosaccades; the latency of antisaccade errors is lower than that of correct antisaccades, but it remains longer than the latency of what is traditionally referred to as anticipations (see Munoz & Everling, 2004, for a review). In contrast, direction errors in the experimental gap conditions of Experiments 1 and 2 had a very short latency (80 ms on average). In addition, contrary to the errors observed in an antisaccade task, they were not visually induced. Saccades launched within 100 ms after the go signal went to the correct or incorrect location with an equal probability, independent of target onset; these

were clearly anticipations. Finally, saccade latencies were not longer in the target-onset condition of the offset-go block than in the stimulus-offset condition of the onset-go block, $t(19) = 0.14$, $p = .89$, although subjects were instructed to saccade away from the offset only in the former and stimulation in these conditions was identical. This was true despite the fact that subjects performed more trials (and, thus, had more training) in the onset-go block.

Most likely, the overall prolongation of saccade latency in the modified gap paradigm resulted from the simultaneous presentation of two peripheral stimuli at the beginning of a trial. The effect is similar to a remote distractor effect, and it could be related to enhanced activation of the fixation system (see Findlay & Walker, 1999; Walker et al., 1997) or a competition (lateral inhibition) between two oculomotor-preparation processes associated with the two potential target locations (see Olivier, Dorris, & Munoz, 1999; Trappenberg et al., 2001; see also Leach & Carpenter, 2001). However, the remote distractor effect was previously found only in conditions where the peripheral distractor was displayed simultaneously with or shortly before or after the saccade target (see Walker et al., 1995), whereas the onset associated with presentation of the peripheral stimuli in our experiments occurred long before presentation of the saccade target. At the same time, it should be noted that saccades in the modified gap paradigm were not reflexive as in classical gap and overlap conditions, but they were rather endogenously determined (see Walker, Walker, Husain, & Kennard, 2000). This probably contributed to prolong saccade latency, but the fact that saccade latency was also increased in the onset-go block (thus, when saccades were exogenously determined) suggests that it could not be the only explanation and that the dual peripheral stimulation from the beginning of a trial until the definition of the saccade target probably also played a role.

Experiment 3: Impact of target onset increases with target uncertainty

In Experiments 1 and 2, we showed that the impact of target onset on saccade latency and saccade accuracy is smaller or even absent if a gap period is introduced before target definition. We attributed these findings to advanced motor preparation in the gap task. An onset at the saccade goal added less to the preparation of a saccade in this condition because in most instances, the saccade parameters were already computed when the luminance change at the target location occurred.

In [Experiment 3](#), we aimed to further substantiate this claim by directly manipulating the motor-preparation mechanisms. Again, we used the modified gap task introduced in [Experiment 1](#), but this time, the number of potential target locations in a trial varied between two, four, and eight, in three separate blocks of trials. As shown in several previous studies, saccade latency decreases, and the probability of express saccades increases, with the predictability of target location in a gap task (e.g., Dorris & Munoz, 1998; Schiller, Haushofer, & Kendall, 2004). These results suggest that motor preparation becomes more likely as the number of potential target locations decreases. They suggest, in turn, that the impact of target onset on saccade latency and saccade accuracy in the gap task should increase with the number of targets, whereas the proportion of anticipatory responses should decrease. On the other hand, an effect of target onset on saccade latency should be observed in the overlap task, but this should be largely unaffected by the number of targets, assuming motor preparation is weaker or absent in this condition.

Methods

Participants

Twenty-four high-school and university students (7 women, 17 men) were paid 7€ for their participation. They were 17 to

24 years old (19 years on average), had normal or corrected-to-normal vision, and were in good health.

Experimental setup and eye-movement recordings

[Experiment 3](#) was run in a different laboratory than [Experiments 1](#) and [2](#), but the same experimental setup and equipment were used.

Task and procedure

Participants performed three blocks, each consisting of 8 practice trials and 96 test trials of the modified version of the gap paradigm. Practice trials were comparable to test trials in all respects. The temporal layout of the task and the stimuli were the same as in [Experiment 1](#). The three blocks of trials differed with respect to the number of cued target locations at the beginning of each trial. Two, four, or eight potential target locations were specified by landmark stimuli. Landmarks could appear at any of eight locations arranged on an imaginary circle with a radius of 4° of visual angle and separated by 45° (see [Figure 7](#)). In the eight-target block, eight landmarks, separated by an angle of 45° , were initially displayed. In the four-target block, four landmarks, separated by an angle of 90° , were initially displayed; there were two arrangement types (square-shaped and diamond-shaped arrangements), equally likely across trials. In the two-

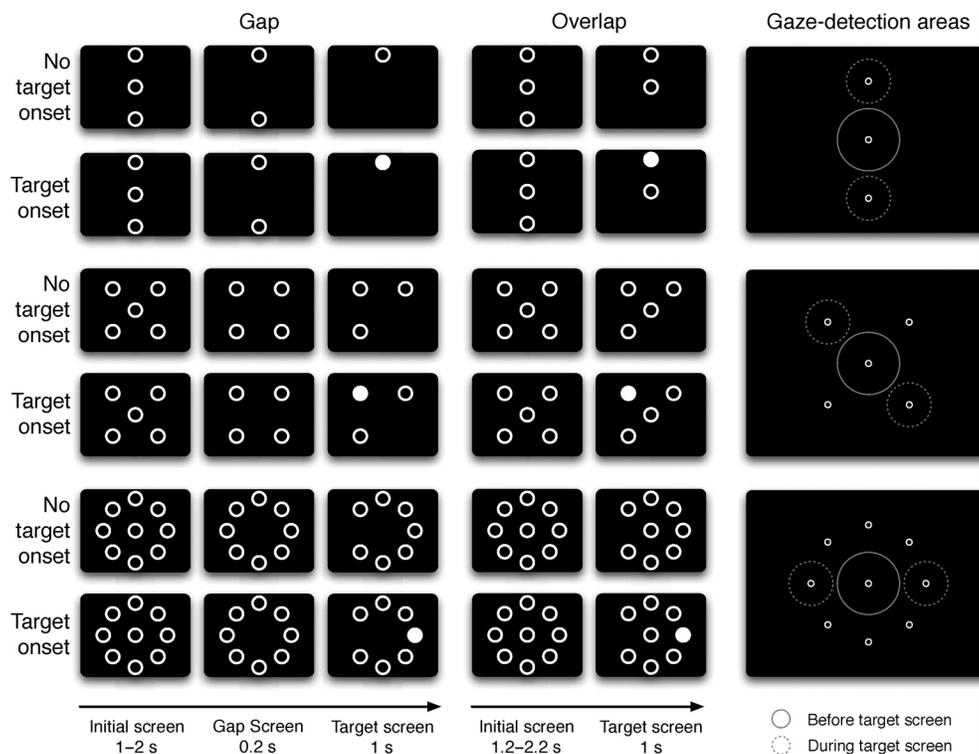


Figure 7. Sequences of visual stimulation in the three blocks of trials of [Experiment 3](#). Stimulus proportions relations are illustrated in the panels to the right; the areas surrounded by gray lines were used for online control of fixation (solid line) and response detection (dashed line). Exemplary target locations were used for illustrative purposes.

target block, two landmarks, separated by an angle of 180° , were initially displayed; there were four arrangement types (horizontal, vertical, and the two diagonal arrangements), equally likely across trials.

As in the above experiments, participants initially fixated the central ring. After 1.2 to 2.2 s of fixation, one of the peripheral rings was removed (go signal) and participants were asked to quickly initiate a saccade to the eccentric target at the mirror position. Fixation offset (gap vs. overlap) and target onset (yes vs. no) were orthogonally manipulated as independent variables within each block of trials, resulting in four conditions (gap target onset, gap no target onset, overlap target onset, and overlap no target onset), and in a $2 \times 2 \times 3$ (two, four, or eight target locations) repeated measures design. Within a block, there were 24 trials in each condition (3 per target location); all conditions were presented in a random order. Blocks were counter-balanced across participants.

Saccadic responses (eye position shifts to either the target or its mirror position) were detected online and terminated the trial if eye position was detected for more than 200 ms in one of two circular areas (diameter of 3°) centered on the two locations. To enable blinking, we used intertrial intervals of 1 s with no visual stimulation.

Trials were aborted if no saccade response was detected within the 1 s after the go signal or if the participant's gaze moved out of a circular region (diameter of 4.24°) centered on the fixation stimulus before the go signal. Aborted trials were recycled and repeated in a random order after the 96 regular trials of a block.

The eye tracker was calibrated (standard 9-point grid) at the beginning of each block of trials and every 30 trials in each block. Every 10th trial, a drift correction was carried out. Before each trial, a fixation spot was displayed at the center of the computer screen. To start a trial, the participant's gaze had to remain within the fixation region for 200 ms. Otherwise, a drift correction was carried out and the trial was started over. If, after drift correction, the

eyes were still not detected within the critical area, the calibration was repeated.

Data analysis

Post hoc saccade detection was performed as in the previous experiments. The first saccade that shifted the gaze into a ring-shaped region (2.5° to 5.5° eccentricity; see schematic illustration in Figure 9) was considered a response saccade. Saccades landing in a circular region (diameter of 3°) centered on the target location were considered correct responses.

Trials on which saccades larger than 1° of visual angle occurred prior to the response saccade were discarded. For all analyses (except Figures 9 and 10 and corresponding analyses), trials with response latencies shorter than 100 ms¹ and response saccades going in the wrong direction were excluded. Some trials had to be excluded due to data loss during eye-movement recording. Two subjects had very few valid trials (less than 25% in at least one condition) and were therefore excluded. Altogether, the remaining 22 participants contributed a total of 4,896 experimental trials (out of 6,336 or 77.3%) surviving the above rejection criteria.

Results

Figure 8A presents mean saccade latencies (and confidence intervals) as a function of fixation offset, number of targets, and target onset. Repeated measures ANOVAs were conducted, with target onset and number of target locations as independent variables. In the gap condition, there were main effects of target onset, $F(1, 21) = 57.49$, $p < .001$, and number of targets, $F(2, 42) = 47.13$, $p < .001$. In addition, the effect of target onset increased with the number of targets, as revealed by a significant interaction between these two variables, $F(2, 42) = 8.14$, $p = .0010$. In the overlap condition, there were again main

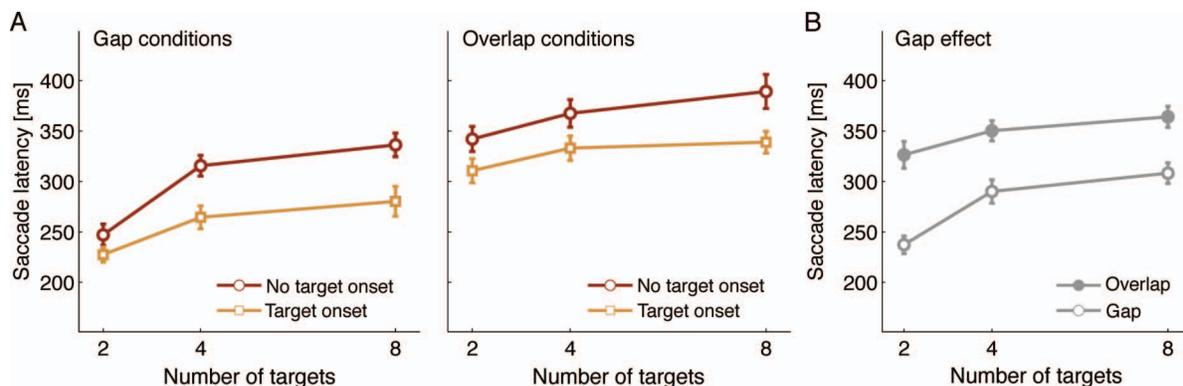


Figure 8. Mean saccade latencies in Experiment 3. (A) Influences of the number of target locations and target onset in the gap and overlap tasks. (B) Influences of fixation offset and number of targets, aggregated across target-onset and no-target-onset conditions. Error bars are 95% confidence intervals.

effects of target onset, $F(1, 21) = 31.66$, $p < .0011$, and number of targets, $F(2, 42) = 9.37$, $p < .001$, but this time, there was no reliable interaction, $F(2, 42) = 2.48$, $p = .096$.

Figure 8B shows mean saccade latency as a function of the fixation-offset condition and the number of targets, aggregated across target-onset and no-target-onset trials. This figure shows that the gap effect decreases with the number of target positions available, as borne out by a repeated measures ANOVA, with condition, target onset, and number of targets as independent variables. Apart from three significant main effects and an interaction of target onset and condition, this analysis yielded an interaction between fixation offset and number of targets, $F(2, 42) = 16.40$, $p < .001$.

As noted in Experiment 1, anticipations may be an index of motor preparation. For this reason, saccade-latency histograms were plotted separately for the 12 factor-level combinations of fixation offset, target onset, and number of targets in Figure 9. The distributions were computed as for Experiment 1. Correct responses were

plotted upward; directional errors were plotted downward, with a distinction being made between the saccades that took the eyes to the peripheral-offset location (light orange and light red) and those that were directed to the remainder (gray) of the target ring (width of 3° ; see schematic in Figure 9 for an illustration of the different color-coded landing areas). This figure shows, first, that the distributions in the two-target condition were very similar to those reported in Experiment 1. Again, anticipations formed a separate mode and they were exclusive to the gap task (in both target-onset and no-target-onset conditions); they were directed toward the target or the contralateral peripheral offset with about equal probability. Second, the proportion of anticipatory responses in the gap conditions strongly decreased with an increasing number of targets. Third, some of the regular-latency saccades were directed to an erroneous location.

To quantify these results, we plotted mean proportions (and confidence intervals) of anticipatory saccade errors in

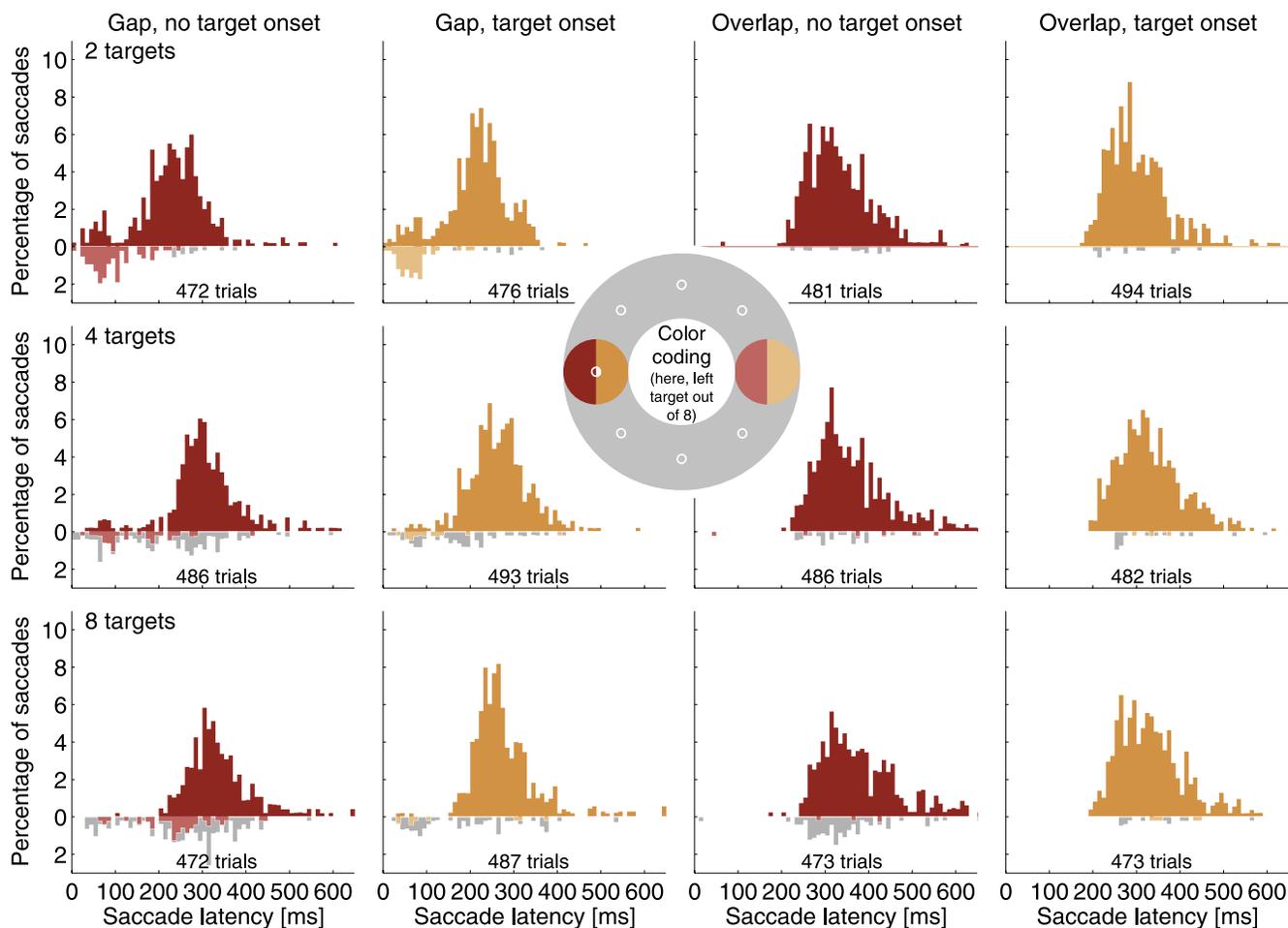


Figure 9. Distributions of saccade latencies for correctly (dark, upward) and incorrectly (light, downward) directed saccade responses in the 12 factor-level combinations of condition, target onset, and number of targets in Experiment 3. Gray areas highlight the share of errors that did not land at the peripheral-offset location but elsewhere on the target ring. Color coding is illustrated at the center of the figure. Binning was set to 10 ms.

the gap condition (latencies ≤ 100 ms) as well as misdirected regular-latency saccades in the gap and overlap conditions (latencies ≥ 130 ms) in the left column of panels in [Figure 10](#). Anticipations were about as frequent in the target-onset as in the no-target-onset condition and decreased significantly with the number of targets in the display. Regular-latency errors became more likely as the number of targets in the display increased. They were more frequent in the no-target-onset than in the target-onset condition, and this difference strongly increased with the number of targets.

In [Figure 10](#), the nine panels at the right depict landing sites of anticipations and misdirected regular-latency saccades as a function of the number of targets (separate panels) and target onset (different colors). Clearly, the direction of anticipatory saccades was not random; they systematically brought the eyes to a potential target location in the trial. The thin lines connecting landing sites to the actual target locations nicely illustrate this by recreating the visual display of a certain condition; for instance, in the four-target condition, errors exhibit a

square or a diamond arrangement, but there are no connections to the intermediate target locations.

In the gap condition, the erroneous saccades with a regular latency were also clearly guided by the visual display. However, in the eight-target condition and, to some extent, in the four-target condition, there were additional errors that landed in between the target and one of its neighbors, suggesting some sort of a center-of-gravity effect (Findlay, 1981; McSorley & Findlay, 2003); this trend was absent in anticipatory responses. In the overlap condition, averaging responses characterized most erroneous saccades; saccades going to a different target location were rather the exception.

Discussion

[Experiment 3](#) yielded further evidence for the motor-preparation hypothesis. First, in line with earlier studies (e.g., Schiller et al., 2004), the gap effect decreased with the number of potential target locations in a trial. Second,

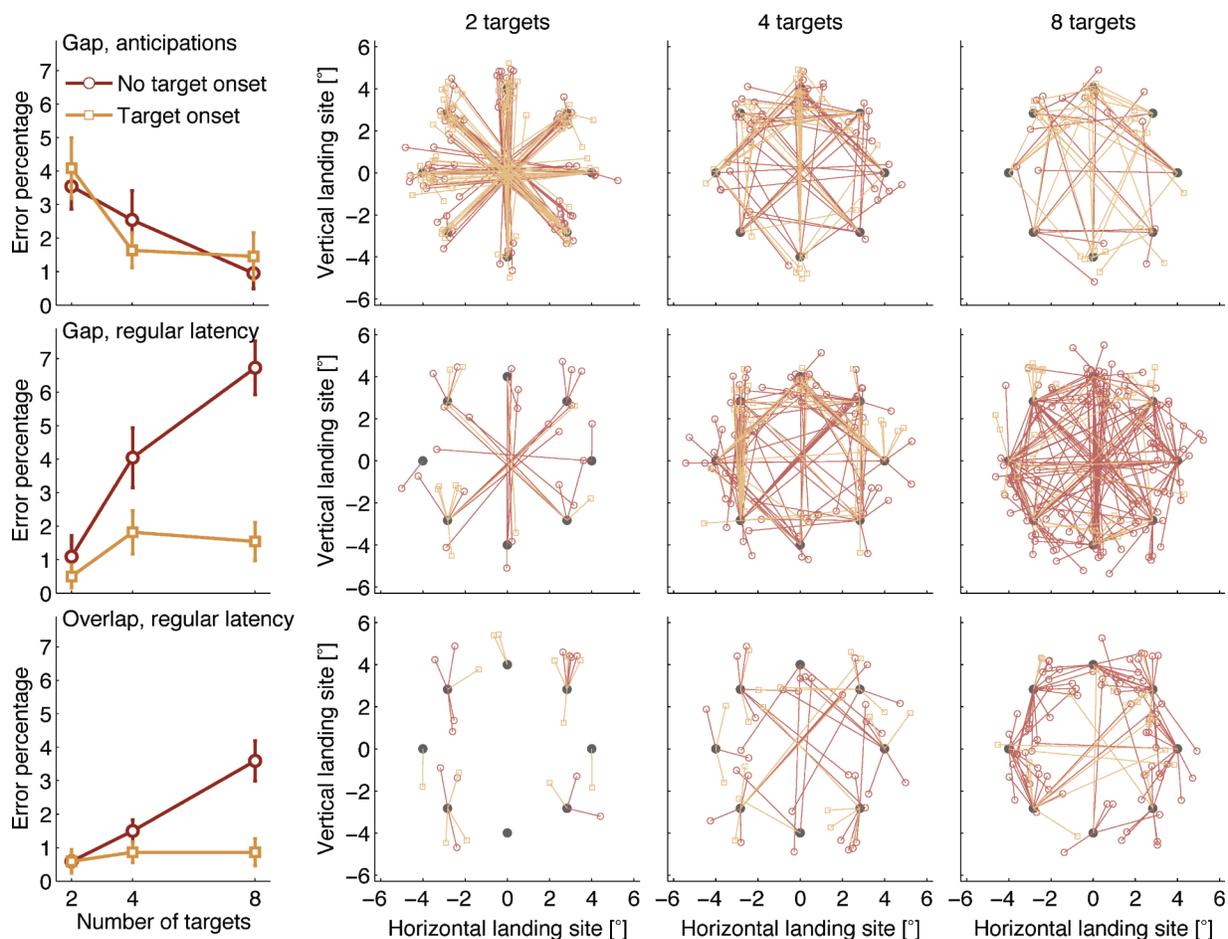


Figure 10. Analyses of anticipations (latencies ≤ 100 ms) in the gap task (first row of panels) and misdirected regular-latency saccades (latencies ≥ 130 ms) in the gap (second row of panels) and overlap tasks (third row of panels) in [Experiment 3](#) as a function of target onset and the number of targets. Panels on the left side display the saccade-error percentage; error bars are 95% confidence intervals. Panels on the right display corresponding saccade endpoints, connected to their actual target locations (gray dots) by thin lines.

target onset had a differential impact on saccade generation in the gap task, depending on the predictability of target location. The influence of target onset was minimal when the target was presented at one of only two possible target locations (see also [Experiments 1 and 2](#)), whereas in the four- and eight-target conditions, saccade latency was reduced in the target-onset condition as compared to the no-target-onset condition. In contrast, the effect of target onset on saccade latency in the overlap task did not vary significantly with the number of target locations. Third, anticipatory saccades were only found in the gap task; their frequency decreased with the number of potential target locations. Furthermore, anticipations did not send the eyes to random locations; instead, they landed on potential target locations in a trial. This confirmed that anticipations resulted from early available saccade programs rather than unlocalized readiness. Direction errors in the regular-latency range also tended to bring the eyes to potential target locations, but these were less likely in the target-onset condition as compared to the no-target-onset condition at least with four- and eight-target configurations. This suggested that target onset was able to compete with preparatory activity when this was weaker or delayed, as was probably the case when the uncertainty of target location was enhanced. Alternatively, it could be that advanced motor preparation was almost never at work under high uncertainty and that misdirected saccades as well as averaging responses resulted from the target location being less and less salient as the number of stimuli increased (e.g., [McSorley & Findlay, 2003](#)).

Thus, as proposed in the motor-preparation hypothesis, there are indeed instances where the saccade metrics are computed before a saccade is required. Such instances occur mainly when the number of potential target locations is low and the gap period gives enough time for the saccade to be prepared in advance (i.e., 200 ms). Note that the present results indicate that these preparation mechanisms may work on a trial-by-trial basis because there were eight interleaved target locations in each block.

However, even if our data clearly suggest that motor preparation contributes to the gap effect, the possibility

that unlocalized readiness also plays a role cannot be completely discarded, although we think it is quite unlikely that this would account for the current findings. As shown in [Experiment 2](#), the presentation of two peripheral landmarks at the beginning of a trial tends to increase saccade latency. In general, prolonged saccade latencies are thought to result from enhanced activity in the fixation system, especially in the theoretical framework promoting the temporal-preparation account ([Findlay & Walker, 1999](#); see also [Walker et al., 1997](#)). It may be the case that the level of activity in the fixation system became greater as the number of potential target locations (or number of displayed landmarks) increased. This may have produced an overall increase of saccade latency in both gap and overlap tasks (see also [McSorley & Findlay, 2003](#)) and could have progressively reduced the chance that the fixation system was disengaged when a saccade was required, increasing, in turn, the effect of target onset in the gap task. However, if this were to be the case, then the effect of target onset should mainly characterize saccades with long latencies. On the contrary, a comparison of the latency distributions obtained in the different conditions of [Experiment 3](#) revealed that the separation between target-onset and no-target-onset distributions occurred as early as 200 ms in the four- and eight-target conditions (see [Figure 11](#)). Furthermore, the corresponding distributions for the two-target condition largely overlapped from about 200 ms. This suggests that effects related to target onset emerged due to the reduced predictability of target location and not due to prolonged fixation times. Thus, contrary to the temporal-preparation assumption, the effects were unrelated to the state of the fixation system.

General discussion

Previous studies have shown that the gap effect cannot be simply accounted for by the reduction of fixation activity due to fixation offset and that preparatory

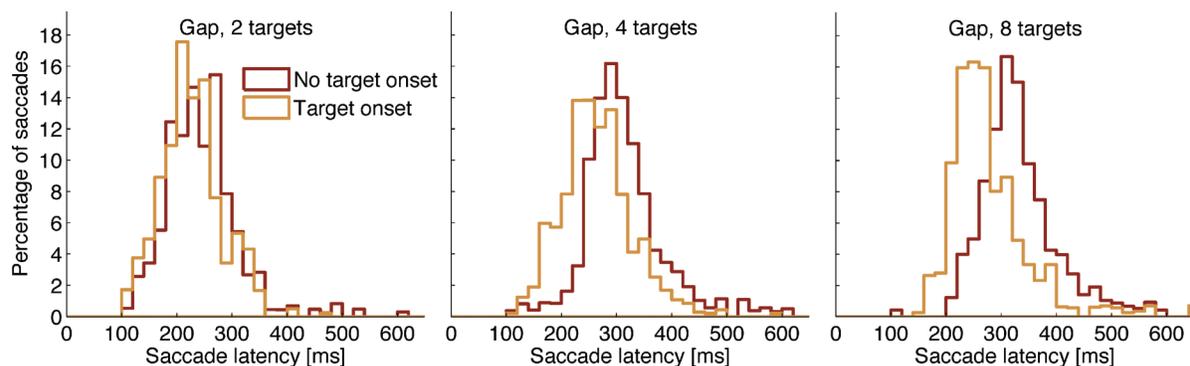


Figure 11. Saccade-latency distributions in gap trials of [Experiment 3](#) as a function of target onset and number of targets. Binning was set to 20 ms.

processes are also involved. To distinguish between localized and unlocalized readiness as assumed in motor- and temporal-preparation hypotheses, respectively, we investigated the roles of target onset and target-location uncertainty in gap and overlap conditions. For this purpose, novel versions of the gap and overlap tasks were designed, in which a peripheral offset signaled the need to saccade to the mirror location. In this way, the onset of the saccade target was manipulated independently of the signal to launch the movement. Under the temporal-preparation hypothesis, an effect of target onset on saccadic performance was expected in both gap and overlap conditions, independent of target-location uncertainty. In contrast, the motor-preparation hypothesis leads to the prediction that saccadic performance should be less affected by target onset in the gap condition as compared to the overlap condition if the location of the target is predictable. Furthermore, the effect of target onset should increase with target-location uncertainty in the gap task.

Our results were overall consistent with the predictions derived from the motor-preparation hypothesis. First, when the saccade target appeared at one of only two possible locations, saccade latency was either not affected ([Experiment 1](#)) or only weakly affected ([Experiment 2](#), offset-go block) by target onset in the gap task, and saccade accuracy was not influenced at all. In contrast, in the overlap condition, saccadic performance was considerably improved in the target-onset condition as compared to the no-target-onset condition. Second, when the number of potential target locations increased ([Experiment 3](#)), the gap effect decreased and the effect of target onset in the gap task became greater, whereas the effect of target onset in the overlap condition remained largely unaffected. In addition, short-latency saccades (<100 ms) could only be observed in the gap task, and the proportion of such saccades increased with the predictability of target location. These anticipations did not send the eyes to any location; rather, they brought the eyes to potential target locations in the trial, confirming that saccade metrics were computed before the definition of the target. These findings strongly suggest, in opposition to a pure temporal-preparation hypothesis, that readiness in the gap task is localized at least to some extent.

On the basis of Paré and Munoz's (1996) motor-preparation hypothesis, we propose that target onset only weakly affected saccade latency in the gap task when the predictability of target location was high because saccades to a given target location (or to given target locations) were already prepared. However, target onset could still fuel a saccade program if the level of motor activity was lower, as in the overlap condition. As suggested by neurophysiological data, target-location uncertainty attenuates preparatory activity in the superior colliculus (SC; Basso & Wurtz, 1997; see also Dorris & Munoz, 1998), whereas low uncertainty enhances motor preparation and favors the occurrence of short-latency anticipatory saccades that are independent of a visual signal

(Dorris & Munoz, 1998). We may therefore assume that, given optimal conditions, saccade metrics begin to be computed following fixation offset. Target onset probably occurs too late in that process to have any impact on either latency or amplitude. In most cases, the saccade program is held until the target location is determined, but in a few cases, the saccade is launched in advance and anticipations (including direction errors) occur.

Because saccade latencies were overall increased in the modified gap paradigm, it was considered possible that target onset failed to influence the saccade parameters in the gap task because of the transient associated with the peripheral offset and the necessity to inhibit a reflexive response toward it. However, as shown in [Experiment 2](#), saccade latencies did not differ when participants were asked to saccade to a flashing target, instead of moving away from a peripheral offset. In addition, saccade latencies in the gap condition were only slightly prolonged when target onset was accompanied by a peripheral offset, whereas the reverse was found in the overlap condition. These findings, which are consistent with previous studies showing that offset transients do not capture the eyes (Boot et al., 2005) but rather facilitate saccade generation to a given target (Todd & Gelder, 1979), suggest that the peripheral offset in our experiments did not interfere with the onset of the target. Note that this argument applies even more to [Experiment 3](#), where the offset transient was less salient due to the presence of additional distractors. In addition, in all experiments, the number of short-latency saccades going in the direction of the offset transient was at chance level ($1/n$, if n is the number of potential target locations in a trial), thus confirming that the peripheral offset did not play a particular role.

Of course, several limitations apply to this study. First, only a single gap duration was tested (i.e., 200 ms), and for the motor-preparation hypothesis to be properly tested, it should be demonstrated that saccade latency is differentially influenced by the timing of target onset. However, the fact that target onset had no effect at a gap duration of 200 ms is consistent with neurophysiological evidence that the activity of SC saccade-related neurons in a gap task is well advanced at about 200 ms following fixation offset because it reaches a maximum toward about 250 ms (Dorris et al., 1997; Munoz et al., 2000). It is also in line with the observation that the strongest gap effect and the greatest number of express saccades can be observed for a gap duration of about 200 ms (Braun & Breitmeyer, 1988; Dorris & Munoz, 1995; Mayfrank et al., 1986; Opris et al., 2001; Saslow, 1967; Tanaka & Shimojo, 2001). According to the motor-preparation hypothesis, there should also be no strong effect of target onset for gap durations longer than 200 ms, whereas for shorter gap durations, target onset should impact on saccade latency in a gap task. This will need to be investigated in future studies.

It must be noted that motor- and temporal-preparation hypotheses are not mutually exclusive and it may be that

advanced computation of saccade metrics occurs only in specific instances. In our experiments, landmarks were continuously displayed from the beginning of a trial until the target was defined. This surely enhanced the contribution of advanced motor programs and increased, in turn, the gap effect: In [Experiment 1](#), the gap effect in the experimental target-onset condition was larger in absolute terms than in the control condition where neither of both potential target locations was primed. In addition, the results in the gap condition of [Experiment 3](#) showed that motor-preparation mechanisms incorporated target-location information on a trial-by-trial basis in our task: Target onset interacted with the number of potential targets in a trial despite the fact that target location was randomly chosen out of eight possible target locations in each block of trials. Studies of express saccades, in contrast, have suggested that long-term target probability may influence the preactivation of certain saccade programs (Dorris & Munoz, 1998; Kingstone & Klein, 1993; Paré & Munoz, 1996; see also Boch & Fischer, 1986; Fischer et al., 1984). Future research will need to determine whether the effect of target onset decreases as long-term expectations build up.

There is reason to believe that motor-preparation-type processes may account for a larger range of findings than simply ours. In most studies that were considered to be in support of the temporal-preparation hypothesis, there was uncertainty about target direction (i.e., the target randomly appeared to the left or to the right of the fixation stimulus) but no uncertainty about target eccentricity (Pratt et al., 2000; Reuter-Lorenz et al., 1995; Ross & Ross, 1980; Ross & Ross, 1981; Tam & Stelmach, 1993). Thus, the facilitating influence of the visual or auditory warning signals that were used in the studies could be attributed to localized readiness (and not to unlocalized readiness). Furthermore, as shown by Kingstone and Klein (1993) in a gap task, presenting the target at a constant eccentricity (but variable direction) reduces the latency of regular saccades as compared to when the target appears at random eccentricities and/or catch trials are interleaved; in addition, it strongly enhances the proportion of anticipatory saccades, a fact that was also noted in the present study and that is consistent with a motor-preparation account (see also Dorris & Munoz, 1998).

On the other hand, advanced motor preparation does not preclude an influence of visual input. First, several authors noted that the high probability of express saccades in the gap task relies on target onset (Dias & Bruce, 1994; Dorris et al., 1997; Edelman & Keller, 1996; Paré & Munoz, 1996; Sommer, 1994; Sparks, Rohrer, & Zhang, 2000), hence suggesting that express saccades are generated if a target-related visual input signal is superimposed upon preparatory motor-related activity. Such merging of two signals has indeed been observed in saccade-related neurons of the SC and could be associated with the generation of express saccades (Dorris et al., 1997; see also Edelman & Keller, 1996). However, these studies

used multiple target locations and sometimes included a broad range of gap durations; this probably weakened motor preparation and favored an influence of target onset on oculomotor performance in the gap task.

In a related manner, it was shown in several previous studies that target luminance influences the latency and accuracy of regular-latency saccades in a similar manner in gap and overlap conditions (Kingstone & Klein, 1993; Reuter-Lorenz et al., 1991). This is in apparent contradiction with the findings of [Experiment 1](#) and suggests that saccades in both gap and overlap tasks are determined based on visual input. However, again, in those experiments, targets appeared at random eccentricities and/or catch trials were interleaved, which probably discouraged or delayed motor preparation; as shown in [Experiment 3](#), the influence of target onset strongly increases with target uncertainty in the gap task. Furthermore, despite the fact that 200-ms gap durations were used in the abovementioned studies, the length of time the fixation point was presented before the warning signal (fixation offset and eventually warning tone) never exceeded 1 s, whereas in the present experiments, it varied randomly between 1.2 and 2.2 s. Short visual fixation probably reduced the likelihood of advanced motor preparation and allowed influences from incoming visual information to occur; in contrast, long visual fixation times, as in our study, urged the preparation of a saccadic eye movement (see Paré & Munoz, 1996).

Conclusions

We found that target onset plays a critical role in the overlap task, whereas its impact in the gap condition is conditional upon the predictability of target location. This behavioral evidence provides support for the motor-preparation hypothesis as initially outlined by Becker (1989) and Kowler (1990) and substantially elaborated by Paré and Munoz (1996). Motor preparation is not the only component involved in the gap effect. As revealed in several studies, fixation disengagement is another fundamental component. In addition, it cannot be excluded that temporal preparation (unlocalized readiness) also contributes to the effect, but its role may not be as critical as it was thought to be in models of saccade generation (e.g., Findlay & Walker, 1999). Future studies will be necessary to further distinguish the contribution of each of the processes to the gap effect and will investigate in more detail the time course of motor-preparation processes. The approach used in this article, which consisted of testing the impact of target onset on saccade latency and saccade accuracy, may be a valuable tool and a nice alternative to already existing neurophysiological measures (e.g., neuronal premotor activity) and their potential behavioral correlates (e.g., the rate of microsaccades; Rolfs, Laubrock, & Kliegl, 2006).

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Footnotes

¹We chose a 100-ms cutoff criterion to eliminate most correct anticipatory responses in the experimental conditions of [Experiments 1, 2, and 3](#) without truncating the distributions of the control conditions in [Experiments 1 and 2](#). We also checked our results with a variety of other cutoff criteria, including 130 ms (removing all anticipations), 80 ms (removing all saccades that could not be visually driven), and no saccade-latency criterion. None but one of the reported results changed using these other criteria (see [Footnote 2](#)).

²This difference in the gap task was the only (!) result that depended on the choice of the latency criterion used to remove correct anticipations (see [Footnote 1](#)). Although there was a small but reliable difference for the 80- and 100-ms criteria, it was not significant for a 130-ms criterion or if no saccade-latency criterion was applied.

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