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Express Attentional Shifts

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"Express" saccades, named for their extremely short latencies, occur more frequently in a paradigm with a "gap" in time between the disappearance of the fixation mark and the appearance of the target to be fixated. To explain this result, it has been hypothesized that movements of the eyes are preceded by movements of attention [Posner (1980) *Quarterly Journal of Experimental Psychology*, *32*, 3–25], and that removing the fixation mark allows attention to disengage from the fovea and to be deployed more rapidly to the peripheral target, thus diminishing saccadic latency [Fisher (1987) *Reviews of Physiology, Biochemistry and Pharmacology*, *105*, 1–35]. We measured attention using extra-foveal vernier acuity performance. Our results provide direct evidence supporting the above hypothesis. First, we found that the rise of performance for increasing cue lead times was much faster in the "gap" paradigm. Second, the time function relating gap duration to discrimination performance was remarkably similar to the one relating gap duration and rate of express saccades reported by Mayfrank, Mobashery, Kimmig & Fischer [(1987) *European Archives of Psychiatry and Neurological Science*, *235*, 269–275]. Third, control experiments showed that it was the disappearance of the fixation mark rather than a non-specific warning that led to more rapid shifts of attention and, thus, to better performance. We therefore conclude that the short latencies of "express" saccades may be based on a mechanism involving unusually rapid shifts of attention.

Attention Eye movements Express saccades Gap paradigm

INTRODUCTION

Although it is generally assumed that our attention is connected with foveal vision and moves along with shifts of gaze, this is not always the case. Helmholtz (1896) observed that he could foveate a fixation spot while attending to a region in the retinal periphery before an array of letters was briefly illuminated by a spark discharge. This enabled him to recognize the letters at the attended site without moving the eyes. Subsequent research using more objective measures of performance (e.g. Eriksen & Hoffman, 1972; Posner, 1980; LaBerge, 1983; Kroese & Julesz, 1989; Nakayama & Mackeben, 1989) have confirmed Helmholtz's original observation. Yet, this does not mean that attention has no customary relation to eye movements when they are used to scan a scene for details.

In 1980, Posner hypothesized that when we make an eye movement to a new location, our attention may reach the new location first and the eyes follow. This concept has been developed further by Fischer and colleagues (Mayfrank, Mobashery, Kimmig & Fischer, 1986; Fischer & Breitmeyer, 1987; Fischer, 1987). To spell out all elements of this hypothesis, shifting the direction of gaze by means of saccadic eye movements entails the following six steps: (1) disengaging attention from the object currently attended to; (2) moving attention to the new point of interest; (3) re-engaging attention there; (4) releasing eye fixation from the currently fixated object; (5) moving the eyes; and (6) re-engaging fixation.

A number of studies examining saccadic latencies bear on this general hypothesis. First it should be noted that in standard saccadic latency experiments (Carpenter, 1977), the observer is presented with a central fixation target. Then two things occur at the same time: the fixation mark disappears and the peripherally placed target appears. The observer is instructed to make an eye movement to the peripheral target as quickly as possible.

Saslow (1967) reported the then puzzling finding that saccadic eye movement latencies could be abnormally short under certain conditions. In his paradigm, the situation was similar to that described above, except that the appearance of the peripheral target was preceded by the disappearance of the fixation point, so that there was an interval of time or "gap" between the two events which had occurred simultaneously in previous studies. For gap durations of approx. 200 msec, saccadic latencies were greatly reduced. Later results confirmed this basic finding (Fischer & Ramsperger, 1984; Kalesnykas & Hallett, 1987) and the special short latency saccades evoked in this situation were called "express" saccades. These findings have also been confirmed in monkeys (Fischer & Boch, 1983; Schiller, Sandell & Maunsell, 1987). More recent studies have

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raised a controversy concerning the existence of a bimodal distribution of saccadic latencies in the gap paradigm (Cameron & Lennie, 1991; Reuter-Lorenz, Hughes & Fendrich, 1991; Wenban-Smith & Findlay, 1991). We would like it to be understood that despite our expedient use of the word "express", the present investigation does not make a contribution to that discussion.

In terms of the scheme outlined by Fischer (1987), the explanation to account for express saccades runs as follows: since it is hypothesized that saccadic eye movements are preceded by a shift of focal attention to the new target, speeding up the deployment of attention to that site will shorten the latency of the eye movement. Accordingly, the disappearance of the fixation mark prior to the appearance of the target favors speeded saccadic eye movements, because the disappearance of the fixation mark allows attention to disengage so that it can begin moving to a new point of interest more immediately.

Additional tests of this hypothesis were reported in three related papers (Mayfrank *et al.*, 1986; Fischer & Breitmeyer, 1987; Braun & Breitmeyer, 1988). These studies employed a fixation mark which, rather than disappearing, remained on. A second spot, which the subject was instructed to attend to, was extinguished prior to the appearance of the peripheral saccadic target. As such, the "gap" was now between the extinction of this non-fixated target and the appearance of the new fixation target. As predicted by the hypothesis, this also led to more express saccades. Thus, it was not the disappearance of the fixation mark *per se* that was critical, but the disappearance of the "attended" stimulus allowing an earlier attentional disengagement. It should be noted that in all these studies, no direct assessment of attention was employed. Attention was inferred only by its influence on eye movements.

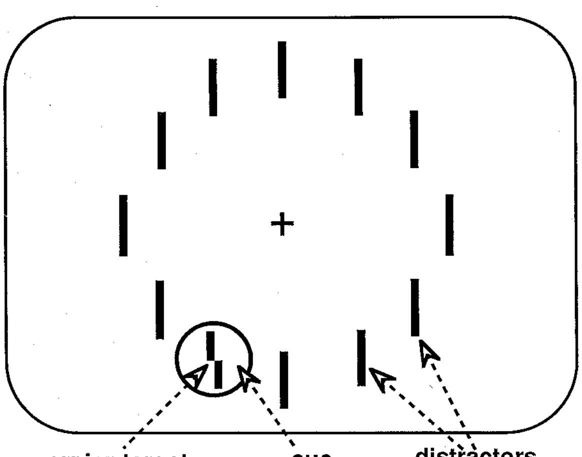

FIGURE 1. Schematic of the circular stimulus array (shown here with only 12 instead of 18 locations). Distractor positions are occupied by vertical lines. Target is a vernier offset whose direction must be identified. Target and distractors appeared at an eccentricity of 5 deg, and their bar width was 6.6 arc min. The luminance of targets and distractors was 40 cd/m^2, that of the background was 0.5 cd/m^2.

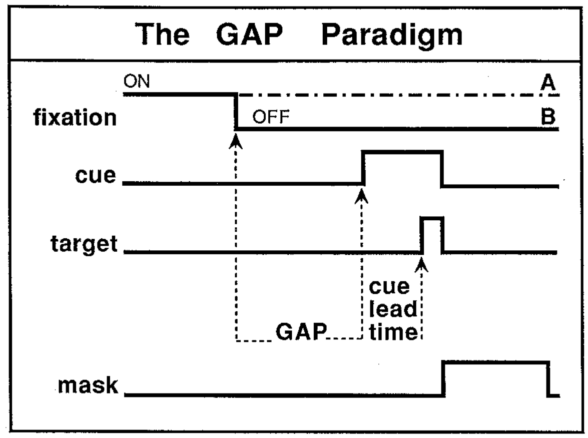

FIGURE 2. Time line diagram showing the sequence of events. "Gap" and "no gap" conditions differ only in the behavior of the fixation point. In the "no gap" condition (line A), the fixation always remained on. In the "gap" paradigm (line B) it goes off before the appearance of the cue. The cue lead time is the time difference between the onset of the cue and the onset of the target display. Gap duration is the time between the offset of the fixation mark and the onset of the cue. The mask duration was always 250 msec.

Having studied the time course of focal attention psychophysically by measuring extrafoveal discrimination performance (Nakayama & Mackeben, 1989), we saw a chance to measure attentional deployment in the "gap" paradigm. Because Fischer's hypothesis assumes that express saccades are due to an accelerated attentional deployment to the target, it was our expectation that the conditions giving rise to express saccades would also lead to more rapid attentional shifts and, thus, a faster rise of the discrimination performance curve.

METHODS

The procedure and instrumentation used here was developed in a previous study (Nakayama & Mackeben, 1989), where a precise characterization of the time–course of peripherally directed focal attention was obtained. The spatial layout of the display is depicted in Fig. 1, while the temporal sequence of events is shown in Figs 2 and 3. Subjects fixated a cross in the middle of a computer display (Commodore Amiga 1000) at a viewing distance of 71 cm.

After an unpredictable interval (1–3 sec), a red disk cue marked one of 18 possible locations in a circular array of 10 deg diameter that would later be occupied by a vernier target with a horizontal offset of 3.3 arc min. The observers' task was to identify the direction of the vernier offset without making any eye movements. Essentially identical experiments where eye movements were monitored indicated that this condition was easily met (Nakayama & Mackeben, 1989). Simultaneous with the appearance of the vernier target, there also appeared a set of distractors, consisting of vertical white bars. The time by which the cue preceded the target and distractor set (the cue lead time) was varied and the percentage of correct vernier identifications was recorded. Cue, target and distractors disappeared simultaneously and were

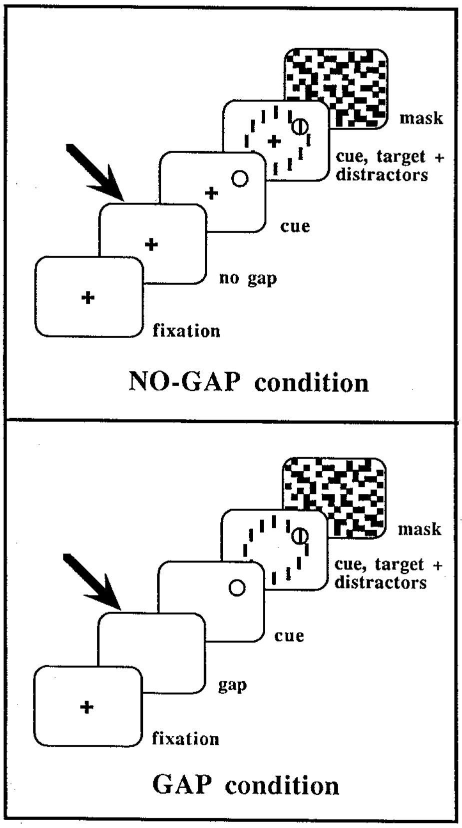

FIGURE 3. Sequence of images presented in the "gap" and "no-gap" conditions. Note that in the gap situation, there is an interval (gap duration) after the fixation marker disappears before the cue appears.

followed by a mask of 250 msec duration. The mask consisted of a full field of small random squares, each subtending 6.6 arc min.

Initially, two conditions were examined, the "no gap" and the "gap" case. In the "no-gap" condition the fixation mark remained on during the entire trial.* In the "gap" condition, the fixation mark disappeared typically 200 msec before the cue appeared. It should be noted that the disappearance of the fixation mark did not allow the subject to predict in which of the 18 locations the target was about to appear, which made anticipatory eye movements useless. Otherwise, the two conditions were identical as can be seen in the diagrams schematizing the sequence of events (Figs 2 and 3). Data showing both conditions for direct comparison were always recorded on the same day.

The experiments were conducted on three healthy subjects (between 20 and 48 yr of age) with 20/20 vision. Two of them were paid subjects with only limited practice in visual psychophysics and were unaware of the purpose of the experiment. Each data point displayed in the graphs is based on at least 100 trials, which were collected in blocks of 20 trials. Blocks of the "gap" and the "no-gap" paradigms were interleaved.

The data are in the form of percent scores and error bars can be calculated as the standard error of a proportion. According to the properties of the binomial distribution, error bars will range from $\pm 2\%$ to $\pm 5\%$ for $N = 100$ for the percent scores obtained in this study. To preserve the clarity of the graphs, we have omitted error bars for all but a few representative points.

RESULTS

As shown in a previous study (Nakayama & Mackeben, 1989), focal visual attention has two aspects: a sustained and a transient component. The sustained component can be directed at will and does not require any target to mark the attended site. Additional improvement in discrimination performance can be achieved if the transient component is added. The transient component is dependent on the relative timing of the appearance of the cue and target. It can take from 50 to 300 msec to effect the shift of the transient component of attention in order to perform optimally in discrimination tasks. This means that the cue has to precede the target display by that amount of time ("cue lead time") and that further lengthening of that time causes performance to decline (for details see Nakayama & Mackeben, 1989). A characteristic course of such a performance function for vernier acuity targets can be seen by looking ahead at the data shown in Fig. 4 and marked "no gap".

It was the rationale of the current investigation to test if the "gap" paradigm indeed speeds up the deployment of attention to the visual periphery. If it did, we should expect to see an improvement of discrimination performance at the rising limb of the function, i.e. at short cue lead times.

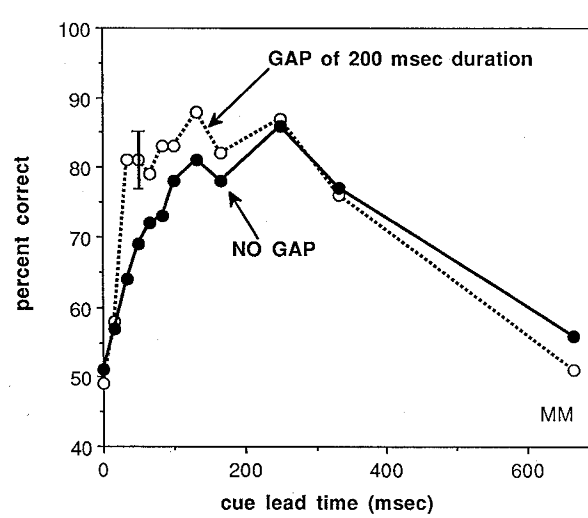

FIGURE 4. Percent correct responses vs cue lead time for subject MM comparing "gap" and "no gap" conditions recorded on the same day. Both curves show the typical decline of performance at cue lead times longer than 230 msec. Note the steeper rise to the performance maximum in the "gap" paradigm.

*It has been reported in the literature that leaving the fixation mark on for some time, while the target is already visible (the so called "overlap" paradigm) prolongs saccade latencies (Kalesnykas & Hallett, 1987). Since our fixation mark remained on during the entire trial, our "no gap" condition is, in fact, an extreme case of the "overlap" condition.

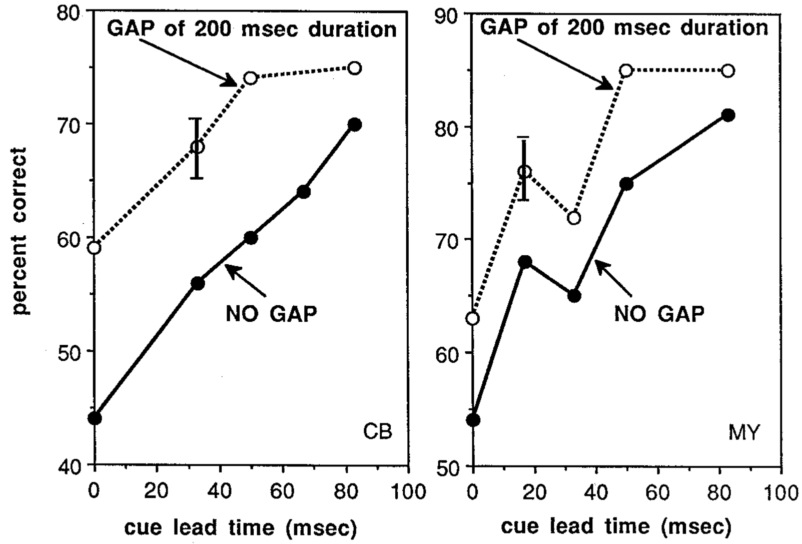

FIGURE 5. Percent correct responses vs a restricted range of cue lead times (the first 100 msec) for the two naive observers, showing similar enhancement of performance at these short cue lead times. The "gap" condition is denoted by a dashed line; "no gap" is denoted by a solid line.

Experiment 1

This experiment was performed on all three of our observers and the results can be seen in Figs 4 and 5. Data for a complete curve showing the widest range of cue lead times was obtained for MM (Fig. 4). Experiments on the two naive observers concentrated on cue lead times under 100 msec, comprising that part of the curve where we expected the important differences to occur. Their data are presented in Fig. 5. As both figures show, the performance curves for all subjects show a significant improvement at short cue lead times for the "gap" paradigm. As such, the results support Fischer's hypothesis, i.e. it is consistent with the view that subjects utilized the 200 msec before the appearance of the cue to disengage their attention from the fovea, thus enabling them to engage it more rapidly elsewhere.

Experiment 2

As a next step, we wanted to find out what gap durations allowed the more rapid attentional deployment and to see if these were comparable to the durations which have been reported to elicit express saccades. We chose a cue lead time of 33 msec because performance at this interval reflects the rapid deployment of attention in the "gap" paradigm. The performance curve for different gap durations is shown in Fig. 6(A). The data show that this subject can improve discrimination performance substantially only if the "gap" durations are within a specific time window which rises rapidly to a peak of just under 200 msec and falls slowly to baseline at about 650 msec. These times are remarkably similar to the "gap" durations which best elicit express saccades. For example, Mayfrank *et al.* (1986) found "gap" duration functions which rose quickly to a peak at 200 msec and which also fell rather slowly reaching baseline around 800 msec [Fig. 6(B)]. Their data from four observers show the proportion of express saccades for different gap durations.

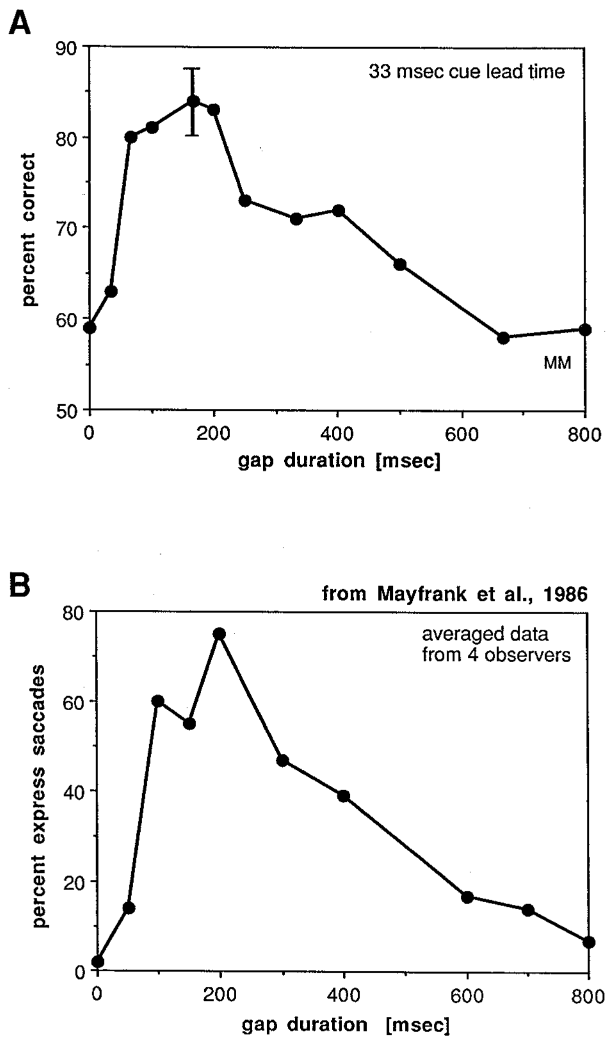

FIGURE 6. (A) This graph demonstrates the dependence of performance on the length of the "gap" duration. Cue lead time remains fixed at 33 msec. (B) Reproduces data obtained by Mayfrank *et al.* (1986), showing the average percentage of express saccades for four human observers as a function of "gap" duration. Reprinted with permission from Mayfrank *et al.* (1986).

Control experiments

In order to clarify the presumed events associated with fixation mark removal, we added a final experiment using MM as an observer. Our motivation was to determine whether the findings reported above were caused by an unspecific alerting or warning effect that could be triggered by the onset of the "gap" but which may have had nothing to do with the offset of the fixation mark *per se*. For example, it could be argued that the gap onset could provide a "ready" signal to the observer, thus alerting him as to the exact start of the trial. In order to deal with this "readiness" hypothesis, we ran two conditions. In both of these new conditions there was no gap but a visible event occurred at the time when the gap would have occurred in the gap paradigm. In the first conditions, rather than turning off the fixation, we simply changed its shape. Thus, at exactly 200 msec before the cue onset, the fixation mark changed from a "+" to an "×". We called this the "fixation change" condition.

In the second condition, we left the fixation mark unchanged but again at 200 msec before the cue onset, we had the whole screen visibly brighten for two frames (33 msec). We called this the "flash" condition. Our view was that each of these conditions should provide equivalent "alerting" as to the exact timing of the trial onset. Thus, each of these two control cases might also be expected to lead to improved performance. If they did not, then it would reinforce the assumption that it was the fixation removal itself, rather than some more non-specific warning property that was critical to produce speeded attentional shifts.

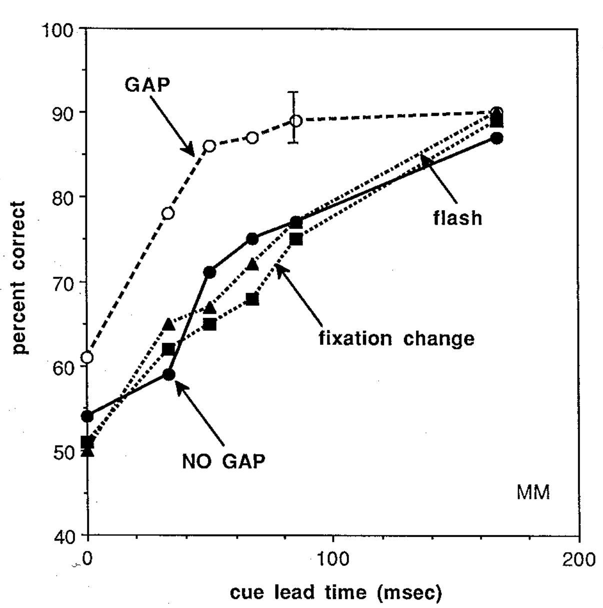

FIGURE 7. Replication of Expt 1 for observer MM (see Fig. 4) adding two new control conditions. The first control (labeled "flash") consists of a flash presented at the same time when the fixation mark went off in the gap paradigm. The second control (labeled "fixation change") consisted of a change in shape of the fixation mark at the same time the fixation went off in the gap paradigm. Note that the four different conditions were interleaved in blocks of twenty trials each. Only the "gap" condition shows enhanced performance.

Figure 7 shows results of both control conditions combined with a replication of the two conditions examined in Expt 1, i.e. the "gap" and "no gap" conditions. It is clear that the data from the "no gap", the "fixation change" and the "flash" conditions are virtually identical, showing a much slower rise than that seen in the gap condition. As such, the results make us confident that the improvement in discrimination performance seen in the "gap" paradigm cannot be explained by the fact that the fixation disappearance acts by marking the time of trial onset.

DISCUSSION

Attention disengagement and re-engagement

We report two new results in this paper. In comparing discrimination performance in a cued vernier acuity task for "gap" and "no gap" conditions, we find that performance rises much more quickly when the onset of the cue is preceded by the offset of a fixation marker. We also find that the time function relating gap time and discrimination performance is very similar to that reported to yield very short latency saccades. Although we see this result as providing strong confirmation for the attentional disengagement hypothesis, it is important to discuss several possible objections that might arise.

First, it might be argued that observers did better in the gap paradigm because they made eye movements to the targets more quickly and were thus able to make better discriminations in central vision. This, however, is not possible. Our major result, the superiority of the "gap" to the "no gap" paradigm, is essentially at a maximum with a cue lead time of just 33 msec, far shorter than any known saccadic latency even those associated with express saccades. Since the cue (and not the fixation offset) provides the only information as to the location of the target among 18 possible positions, saccadic eye movements could not be made in this short time.

Second, it might be argued that the boost in performance is not attentional, but sensory in nature, that somehow the offset of the fixation point facilitates target discrimination at the cued site via some non-attentional mechanism. This possibility becomes exceedingly remote if we think quantitatively, in terms of the differences in retinal position and in time. In terms of retinal location, the target was always on the perimeter of a 5 deg radius circle, requiring a very strong interaction between the offset of a very small fixation cross and a target 5 deg away. In terms of time, the gap duration of 200 msec provides the greatest difference between gap and no-gap performance and very large effects of the gap can still be seen at 500 msec [see Fig. 6(A)]. To our knowledge, no sensory interaction has been seen over such a large distance or over such large differences in time.

Third, one could argue that the results are due to the fact that fixation offset alerted the observer as to the exact timing of the target appearance, thereby improving performance. This readiness hypothesis, however, has been systematically addressed by the experimental data shown in Fig. 7. We show that other events which would thus be expected to "alert" the observer do not lead to a boost in performance at the cued site.

Having dealt with this list of possible alternative explanations, we feel more secure in attributing our results to a more speedy deployment of attention to the periphery allowed by an attentional disengagement at the fixation. We think this result stands on its own and provides direct information as to the conditions which lead to attentional shifts.

The role of attention in generating eye movements

Our primary motivation in the current paper, however, was to establish a stronger connection between attention and eye movements, specifically to test the hypothesis regarding the role of attentional disengagement in the production of express saccades. Prior to the present paper, studies attempting to link these two processes, were restricted to the measurement of saccadic latencies only and speeded attentional processes were only inferred. In this paper, we provide an independent measure of attention at the target site, thus providing information that was previously missing. Three very specific experiments were conducted and in all three, the data were in close accord with what one would predict from the disengagement hypothesis.

Not only did we see a more rapid deployment of attention as predicted (Figs 4 and 5), but we also found a remarkable similarity between the time function relating gap duration and express saccade frequency and that relating gap duration and attention, measured psychophysically. Finally, our control experiments indicated that it was the release of fixation, and thus attention, from the fixation mark that led to rapid attentional shifts, not just any event marking that point in time.

Taken together, we argue that these results strengthen the ideas proposed previously (Posner, 1980; Fischer, 1987), and provide new evidence for the putative role of attention in initiating saccadic eye movements.

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