Effects of structured non-target stimuli on saccadic latency

Brian J. White, Karl R. Gegenfurtner, Dirk Kerzel

Justus-Liebig-Universität
Allgemeine Psychologie
Otto-Behaghel-Str. 10F
D-35394 Giessen
Germany

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Address for correspondence:

Brian J. White
Justus-Liebig-Universität Giessen
Abteilung Allgemeine Psychologie
Otto-Behaghel-Strasse 10F
D - 35394 Giessen

Fax: +49 (0) 641 – 9926119
Email: brian.j.white@psychol.uni-giessen.de
Abstract

It has been suggested that the remote distractor effect is the result of non-target stimulation of a central region representing a collicular fixation zone near the time of target onset. The distributed network of the cells responsible for this effect is believed to extend over a large area, responding to distractors up to 10 deg in the periphery. Several studies also implicate the superior colliculus as the substrate behind an inhibited saccadic response due to a display change. We investigated this further by using a patch of pink noise of various sizes as a non-target stimulus. We show that the onset of a small patch (2.3 x 2.3 deg) of centrally displayed pink noise can produce a significant increase in saccadic latency to a simultaneously presented peripheral Gabor-target. In contrast, a large patch (36 x 36 deg) of pink noise did not increase latency despite the fact that it also stimulated the region representing the fixation zone. Furthermore, only the large patch of noise facilitated latency when presented prior to target onset. We also examined the effect of patch sizes between these two extremes and found a steady decrease in latency as patch size increased. This confirms that non-target stimulation of the region representing the fixation zone near the time of target onset is not in itself sufficient to produce the increase in latency typically found with remote distractors. The results are consistent with the idea that only a spatially confined object leads to a discharge of collicular fixation neurons.

Key words: Remote distractor effect, pink noise, fixation zone, figure-ground segregation
Introduction

Saccadic eye movements rapidly center a peripheral target at the retinal position of highest acuity, the fovea. The latency at which this occurs is highly variable and is affected by specific experimental conditions. It is well known for example that the offset of a fixation point 100 to 200msec prior to the onset of a target can significantly reduce saccadic latencies (“gap effect”, Saslow, 1967), and under certain circumstances can produce a bimodal distribution of response times, the first mode being very fast with a peak around 100msec (“express saccades”, Fischer and Ramsperger, 1984).

In contrast, the onset of a non-target stimulus near the time of target onset can increase saccadic latency and eliminate express saccades (Braun and Breitmeyer, 1990; Lévy-Schoen, 1969; Olivier, Dorris and Munoz, 1999; Walker, Deubel, Schneider and Findlay, 1997; Walker, Kentridge and Findlay, 1995; Weber and Fischer, 1994). This “distractor effect” was most often reported with a non-target stimulus appearing at the mirror-symmetric opposite hemifield of the target, but it is also known to occur at various spatial locations (Walker et al., 1997), with multiple distractors (Weber and Fischer, 1994), and more recently with respect to smooth pursuit latency (Knox and Bekkour, 2004). Weber and Fischer (1994) for example measured the proportion of express saccades (in a gap paradigm) to an oriented target-line 4.5 deg to the right of fixation during the simultaneous onset of a large number of distractors of another orientation. The result was a pop-out display containing approximately 23 by 30 items, extending 15 deg vertically by 20 deg horizontally. Weber and Fischer found that express saccades were eliminated in this case. They then compared this to a condition in which only 2 distractors appeared foveally (0.5 deg on either side of fixation) and found nearly the same reduction in express saccades. They explained the results in relation to the so-called “dead zone”
for express saccades (Weber, Aiple, Fischer and Latanov, 1992), a finding in which express saccades are eliminated to targets appearing within the central 2 deg visual angle. Along these lines, Weber and Fischer (1994) suggested that non-target stimuli appearing in this region might also inhibit rapid saccades to a peripheral target by reactivating foveal attention following its prior disengagement from the offset of the fixation point.

The superior colliculus (SC) is believed to be an important neurological substrate underlying several known effects on saccadic latency (Munoz and Wurtz, 1993b, 1995a), in particular the gap effect, but also the remote distractor effect (Findlay and Walker, 1999; Walker et al., 1997). This structure is retinotopically organized, and cells at the rostral end (a region extending approximately 2 deg foveally) are known to play a significant role in visual fixation (Munoz and Wurtz, 1993a). Hence this region was termed the fixation zone. Cells here show increased firing rates during active fixation, and pause during saccades. This pause is believed to be necessary for saccade generation, and the removal of a visual fixation stimulus causes a break in activity that results in the latency decrease seen during a gap paradigm (Munoz and Wurtz, 1993b, 1995a).

Throughout the remainder of the intermediate SC are saccade-related cells, some of which are directly related to the movement itself (so called burst neurons), and others that show a long lead of low frequency activation before a saccade (so called buildup neurons), which are believed to be related to some form of saccade preparation (Dorris, Paré and Munoz, 1997; Munoz and Wurtz, 1995a). The fixation zone is thought to form the rostral end of the buildup layer, and the activity of fixation- and buildup-cells is believed to compete against one another in a push-pull relationship through lateral inhibitory connections (Munoz and Istvan, 1998; Munoz and Wurtz, 1995b). In addition, the level of buildup activity (i.e., discharge rate) is inversely related to saccadic latency
(Dorris et al., 1997), and it has been suggested that collicular input from higher cortical areas (e.g., frontal eye fields, Segraves and Goldberg, 1987; parietal cortex, Lynch, Graybiel and Lobeck., 1985) also influences this activity (Munoz and Wurtz, 1995b), thereby affecting latency.

A link between the fixation zone and the remote distractor effect was suggested by Walker et al. (1997). They argued that if fixation offset can decrease latency by decreasing activity in the fixation zone (allowing the early generation of a saccade), then visual onsets (i.e., distractors) within a certain central region might increase latency by increasing fixation cell activity at a critical time when a peripheral target appears. This possibility was implied earlier by Munoz and Wurtz (1993b) through a proposed link between the collicular fixation zone and the dead zone for express saccades (Weber et al., 1992). Munoz and Wurtz suggested that the onset of a stimulus within this region might also reactivate fixation cells, reducing the probability of express saccade generation.

In addition, Walker et al. (1997) have suggested that the fixation zone may extend more peripherally than previously thought. They reported increased latencies with distractors presented in various spatial locations as much as 8 deg peripherally (though the greatest effect was for central distractors), with the exception of a ~20 deg target axis in which distractors instead modulated saccadic amplitude: that is, saccadic landing positions were between the target and distractor (“global effect”, Deubel, Wolf and Hauske, 1984; Findlay, 1982). Walker and colleagues have therefore suggested that the fixation zone may extend as much as 8-10 deg peripherally, and this effect has been similarly shown in terms of smooth pursuit latency (Knox and Bekkour, 2004). Findlay and Walker (1999) have recently incorporated this finding into their model of saccade
generation, and proposed that the effect is visually direct and not subject to cognitive influences.

There is also evidence that lateral interactions between competing sub-populations of active saccade-related collicular neurons can account for the remote distractor effect (Olivier et al., 1999; Trappenberg, Dorris, Munoz and Klein, 2001). Under this scheme, a saccade target and a remote distractor are believed to cause two separate locations of activation on the collicular motor map. Then through the lateral inhibitory network along the intermediate collicular layers (Munoz and Istvan, 1998), the locus of target-related activity is delayed from reaching the level necessary for triggering a saccade.

There appears then to be a growing consensus that virtually any form of visual stimulation near the time of target onset has a direct affect on a saccadic response, in particular saccadic latency, as evidenced by several studies (e.g., Baccino, Jaschinski and Bussolon, 2001; Findlay and Walker, 1999; Reingold and Stampe, 2000, 2002; Vergilino-Perez and Findlay, 2003; Walker et al., 1997; Weber and Fischer, 1994). Most of these studies suggested the SC as a possible substrate behind their effect. For example, Reingold and Stampe (2000) have reported an effect in which observers, during either a visual search task or a reading task, show an inhibited saccadic response (so called “Saccadic Inhibition”) due to a short display-change (e.g., a homogeneous blank field flashed for 33 msec). They suggested two means through which collicular activity might account for this effect: Either the onset of the display stimulated competing sub-populations of build-up neurons, which through lateral inhibition might have delayed a saccadic response (Munoz and Istvan, 1998), or the display change stimulated an extended fixate system (Walker et al., 1997). Along similar lines, Baccino et al. (2001)
reported that a bright background flicker (50Hz) starting at target onset and ending at saccade onset (i.e., during the latency period) increased saccadic latency to a peripheral laser point target (an effect particularly pertinent to concerns of CRT monitor use). They suggested that the background flicker acted like a display of remote distractors (in line with Walker et al., 1997), and they too implicate the SC as the neurological substrate behind the effect.

Although direct stimulation of neurons at the rostral pole of the SC stops saccades (Munoz and Wurtz, 1993b), it is not clear whether visual events of any sort within the area representing the fixation zone should increase saccadic latency. In particular, it is not known whether these neurons discriminate between stimulation arising from spatially discrete elements (potential objects) and a background (a texture). Recall that Weber and Fischer (1994) reported an elimination of express saccades to a target in a large field of homogeneous distractors or simply with a distractor presented foveally on either side of fixation, presumably because the items stimulated the dead zone in either case. Weber and Fischer suggested that any display that affords pop-out might inhibit express saccades via control from the attention system allowing more efficient target detection. On the other hand, McPeek and Schiller (1994) have reported that rhesus monkeys can make express saccades to a target in a display that affords pop-out, provided the number of distractors is very high, making the individual non-target elements less salient as the display begins to form more of a texture. It appears then that not all forms of non-target stimulation of the fixation zone result in increased saccadic latency. One possibility is that non-target elements in larger displays may have to be clearly distinct before they are interpreted by the visual system as distractors.
The purpose of this research was to directly test whether non-target stimulation of the region representing the collicular fixation zone is sufficient to produce an increase in saccadic latency, even if such stimulation is extended to cover a region beyond 2 deg of the fovea. If this is the case, one might predict that a large form of distraction covering most of the visual field would increase saccadic latency as much as a small, foveally presented distractor (as suggested by Weber and Fischer, 1994). However, if non-target stimulation has to be a spatially confined element to produce a distractor effect, we may expect different results if we present a large spatially continuous non-target (e.g., a texture). The research of McPeek and Schiller (1994) has shown that non-target stimuli must be visually discrete elements in order to suppress express saccades, and it may be implied that only in this case does the visual system interpret such stimuli as distractors. Thus a large texture should not increase latencies despite stimulation of the foveal fixation zone near the time of target onset. However, a reasonably small, foveally presented, patch of this texture might nonetheless be interpreted as a salient element. In this case, we predict that saccadic latency should increase.

In the present study, non-target stimulation was in the form of a patch of pink noise (sometimes referred to as 1/f noise as it is a random noise texture whose power spectrum is approximately equal to 1 over the frequency). The power spectrum of pink noise is similar to natural images (which is approximately 1/f², Burton and Moorhead, 1987) making it an interesting setting for examining saccade target selection in its own right. The target was a stationary Gabor patch (4 cycles/deg, SD = 0.7 deg²), which always appeared 4, 7 or 10 deg right or left of fixation. Sometimes the non-target stimulus consisted of only a small central patch of noise, leaving the target visible against a neutral gray background (see Figure 1A). We compared this with a large patch of noise
(essentially a background change), in which case the target was embedded in the noise (see Figure 1B). We also examined the time-course of these effects, and the effect of varied patch-sizes between these two extremes.

-Insert Figure 1 here-

Methods

Observers

Two authors plus 3 additional observers took part in each experiment. All observers had normal or corrected to normal visual acuity, and were experienced in psychophysical and saccade related experimental tasks. Observers ranged in age from 20 to 35 years of age.

Stimuli

The target was a vertically oriented stationary Gabor patch (4 cycles/deg) with a gaussian standard deviation of 0.7 deg². The central fixation stimulus was a bull’s-eye (i.e., black with a diameter of approximately 0.4 deg, and a neutral gray center of the same luminance as the background, 32 cd/m²). Distractors consisted of a patch of pink noise, which were generated offline using a MATLAB function (the size of the patches will be described in each experiment). Twenty-four randomly generated distractor patches were available for random selection on each trial of each experiment. Targets and distractors were presented at 50% contrast and had the same average luminance as the neutral gray background on which they were displayed (32 cd/m²). Previous testing revealed that contrast threshold of the target in the noise was slightly elevated relative to targets on the neutral gray background.

Equipment
Stimuli were displayed on a 21 inch CRT monitor (ELO Touchsystems) driven by an ASUS V8170 GeForce 4 MX440 graphics board at a non-interlaced refresh rate of 100 Hz. The resolution of the monitor was set at 1280 x 1024 pixels which corresponded to physical dimensions of 37cm wide by 29.6cm high. At a viewing distance of 47cm, the display occupied a retinal area of 45 deg horizontally and 36 deg vertically. Eye-movements were measured using EyeLink II (video-based tracker from SR Research Ltd., Mississauga, Ontario) at a sample rate of 250Hz.

Procedure

Calibrations were made before each block of trials (approximately every 90 to 140 trials), and consisted of fixating 9 consecutive bull's-eye stimuli at various locations on the screen. Average spatial accuracy for each calibration was maintained at 0.25 deg or lower.

Figure 2 shows the sequence of a trial for each experiment. The fixation stimulus was present before the start of each trial. Observers had to fixate this stimulus, and then initiate the trial whenever they were ready by pressing a key on a game-pad. This allowed for a drift correction procedure at the start of each trial. In the event that observers were not fixating accurately (within 1 deg), an error-tone was presented, and the trial had to be reinitiated. In all experiments, the fixation was extinguished 1000msec after the start of a trial, and the patch of pink noise, when present, was onset at the same time in the same central location (with the exception of Exp. 1 in which the distractor appeared centrally, or 4, 7 or 10 deg above or below the fixation location). A control condition in which no distractor appeared was also always employed. With the exception of Experiment 3, the target also appeared simultaneously with these events, 4, 7 or 10 deg randomly left or right of fixation, and remained present for 1000msec. In Experiment 3 we varied the
onset of the target (-100, -50, 0, 50 or 100msec) relative to fixation offset and noise patch onset. The result was a 3 x 5 factorial design (1 control and 2 distractor conditions x 5 target SOAs).

Observers were simply requested to make an eye movement to the center of the target when it appeared, and that both speed and accuracy are equally important. The observer’s head was stabilized by a chin rest. Each observer completed at least 18 trials per condition of each experiment. Eye position and event data were recorded, and all analyses were done offline.

**Analyses**

Trials with direction errors, or eye-traces that drifted more than 1 deg vertically or horizontally from fixation prior to a saccade, or more than 2 deg vertically during a saccade, were removed from analyses. In terms of accuracy, we calculated both signed and unsigned error of individual trials. Signed error was the distance of a saccade landing position from the target (in deg) along the horizontal axis, such that undershoots were represented as negative values, and overshoots were represented as positive values. Unsigned error was the absolute value of the distance of the saccade landing positions from the target (in deg). Latency was the time between target onset and the onset of the first saccade, which was based on a velocity criterion of 30 deg/sec or greater. No outlier procedure was used, but we removed trials with an error greater than 3 deg, as well as trials with latencies greater than 600msec or less than 80msec (saccades less than 80msec are presumably anticipatory; Wenban-Smith and Findlay, 1991). With these criteria, less than 5% of the total number of trials was removed, indicating that the target was clearly visible, and that the task was reasonably easy regardless of distractors.
We derived each subject’s median latency, and median signed- and unsigned error, for each condition. It should be noted that all figures report the mean of the subjects’ median values. With the exception of Experiment 1, the data were collapsed across target positions (i.e., eccentricities and left versus right locations). We employed the various target eccentricities only for the purpose of decreasing predictability of the target’s location.

**Experiment 1**

The purpose of Experiment 1 was to demonstrate that the distractor effect may be obtained with a small patch (64 x 64 pixels, 2.3 x 2.3 deg) of pink noise as a distractor stimulus. When present, the distractor patch appeared either foveally, or 4, 7 or 10 deg above or below fixation along the vertical meridian, while the target appeared simultaneously along the horizontal meridian (randomly at one of the previously mentioned target locations). Walker et al. (1997) had previously shown distractor effects for non-target stimuli in various spatial locations (including the vertical axis), with the strongest effect for foveally presented distractors. We predicted a steep effect of eccentricity as well, with the strongest effect for the central distractor.

**Results and Discussion**

**Accuracy.** Figures 3A and B show mean signed and unsigned error, respectively, as a function of distractor eccentricity. There appeared to be more undershooting in the presence of peripheral distractors (Figure 3A, signed error), so we ran a repeated-measures ANOVA on the 5 conditions represented in the graph (i.e., 1 no-distractor control, and 4 distractor eccentricities). However, the test was not significant, $F(4,16) = 1.72, p = .19$, indicating that the distractors did not significantly affect saccadic accuracy.
Presumably distractors outside ~20 deg of the target axis have no effect on accuracy (Walker et al., 1997). Our data are consistent with this.

*Insert Figure 3 here*

**Latency.** Figure 3C shows the mean saccadic latency as a function of distractor eccentricity for each target eccentricity separately (thin lines), and for the combined target eccentricities (solid, thick line). Presumably the remote distractor effect is also influenced by the ratio of distractor-to-target eccentricity (Walker et al., 1997). This does not appear to be the case in our data (Figure 3C, thin lines). The latency pattern looks nearly the same regardless of target eccentricity. If such an effect is present in our data, we should see a significant interaction between target and distractor eccentricity, so we ran a 3 (target eccentricity) x 4 (distractor eccentricity) repeated-measures ANOVA to test whether this was in fact the case. The effect of target eccentricity was not significant ($F(2,24) < 1$), and more importantly the interaction between target and distractor eccentricity was also not significant, $F(6,24) = 1.33$, $p = .28$. This indicates that any effect of the distractors did not vary as a function of target eccentricity. The effect of distractor eccentricity was however significant, $F(3,24) = 14.19$, $p < .001$. This can be clearly seen in Figure 3D, which shows the difference between the distractor conditions minus the control condition (combined target eccentricities). There appeared to be a clear increase in latency for the 0 deg distractor condition relative to the control condition, but there was no obvious difference across the peripheral distractor conditions (> 0 deg), so we collapsed these into one mean, and then ran two Bonferroni adjusted paired-samples t-tests (0 deg distractor with the control, and peripheral distractors with the control). Only the central distractor showed a significant increase in saccadic latency relative to the control condition, $t(4) = 3.66$, $p = .02$. Latency for the combined peripheral distractors
was not significantly different from the no-distractor control condition, $t(4) = 2.77$, $p = .08$. In short, a small patch of centrally displayed pink noise increased saccadic latency by approximately 34msec.

The lack of a significant effect for more peripheral distractors may be inconsistent with the idea of an extended fixation zone (Walker et al., 1997). However, part of the support for the idea comes from the fact that the magnitude of the effect is modulated by the distance of the distractor from the fovea, as well as physiological evidence that the proportion of direct projections from the SC to omnipause neurons in the brainstem (the activity of which is directly related to saccade initiation and termination) decreases gradually as we move away from the rostral pole (Gandhi and Keller, 1997). While our effect for peripheral distractors was not significant, it is reasonably within the range of latencies reported by Walker et al. (1997) with similar target and distractor positions (i.e., approximately 10 to 20 msec). Nonetheless, our effect appears to drop dramatically between the central and peripheral distractors, and then remains level up to a distractor eccentricity of 10 deg. This might suggest the involvement of separate mechanisms, one involving the fixation system (though not extending to the point proposed by Walker et al., 1997), and the other involving inhibitory lateral interactions along the remainder of the collicular motor map (Olivier et al., 1999).

We agree with Tam (1999) that an increase in fixation activity by a peripheral stimulus appears counterintuitive. Evidence against an extended fixation zone has also been suggested by the work of Fendrich, Demirel and Danziger (1999). They employed a gap/overlap paradigm in which the fixation stimulus was a square formed by 4 peripheral anchor points appearing 1, 2 or 4 deg from the square’s center (the target appeared 6 deg left or right of center). These authors found that saccadic latency was only facilitated
(between a gap 0 and continuous overlap condition) with fixation anchors less than 2 deg, which is inconsistent with the idea of an extended fixation system.

**Experiment 2**

Once we established a significant distractor effect using a small patch of pink noise, we then compared this to the onset of a patch covering a larger area of the visual field (36 x 36 deg, essentially a background change). In this case the target was embedded in the noise (Figure 1B). Previous testing revealed that the visibility of the target is slightly reduced in the noise relative to a neutral gray background\(^1\). Recall that Weber and Fischer (1994) employed a similar comparison using oriented lines as stimuli (large versus small central display), and found no differences between the conditions (in terms of the proportion of express saccades\(^2\)). Given this fact, and the assumption that visual stimulation of an extended fixation zone can account for the effect of remote distractors (Walker et al., 1997), one might predict that latencies would increase in either the small or large patch condition. However, if non-target stimulation has to appear as discrete elements to be interpreted as a distractor, as suggested by the research of McPeek and Schiller (1994), the large pink noise texture employed here should not increase saccadic latency.

**Results and Discussion**

**Accuracy.** Figures 4A and B show mean signed and unsigned error, respectively, along the target axis for each condition. There is clearly no difference between either of the conditions. Accuracies were virtually identical regardless of the presence of non-target stimulation.

-Insert Figure 4 here-
Latency. Figure 4C shows mean latency for each of the conditions, and Figure 4D shows the size of the effects. There was a significant effect of condition, $F(2,8) = 12.98$, $p < .005$. Subsequent Bonferroni adjusted t-tests revealed that only the small patch significantly increased latency, $t(4) = 3.92$, $p = .017$.

As predicted, non-target stimulation of the region representing the fixation zone may be necessary, but it is not in itself sufficient to produce the increase in latency typically found with remote distractors. Moreover, we know visibility of the target embedded in the noise was reduced relative to a neutral gray background\textsuperscript{1}. We made no attempt to control for this so as to make the test more conservative.

**Experiment 3**

Experiment 3 was designed to examine the temporal dynamics of the effects found in Experiment 2. We used both the small (2.3 x 2.3 deg) and the large (36 x 36 deg) non-target stimulus, the onset of which remained simultaneous with fixation removal. The only thing that changed was that the target could appear at various onset asynchronies up to 100msec before or after the distractor and fixation events (Figure 2). Thus, in the absence of a non-target stimulus (i.e., the control condition), target SOAs greater than 0 resulted in a gap condition, and target SOAs less than 0 resulted in an overlap condition.

With this design, it could be argued that the onset of a central non-target stimulus (in particular, the small patch of pink noise) simultaneous with fixation offset acts as an extended fixation event. However, the switch from a fixation stimulus to a distractor is perhaps better defined as a change-event (Ross and Ross, 1980). This change remains central to our study’s primary purpose: that is, whether a switch from a fixation stimulus to another form of raw visual stimulation necessarily inhibits a saccadic response
(presumably by sustaining the tonic firing rate of fixation neurons). In addition, a change or an onset at fixation has been shown to produce the same increase in saccadic latency (Ross & Ross, 1980; see Walker et al., 1997, who noted this as well). Thus this experiment should allow us to test how the effect of each change-event (i.e., non-target stimulus) might vary with target SOA, in comparison to the no-change control condition. The control condition is expected to have its own effect of SOA as we move from fixation gap to overlap, and the question is what additional effect will the simultaneous change-event have, if any?

Ross and Ross (1980) have shown that a change at fixation prior to the onset of a saccade target can act as a warning signal, provided the interval is greater than 100 msec. When the change- and target-event were simultaneous, the result was a latency increase consistent with the central distractor effect reported by Walker et al., (1997), and our current study. Braun and Breitmeyer (1990) have shown that the reappearance of a fixation stimulus 100 msec or more before target onset can also facilitate saccade latency relative to its reappearance simultaneously with the target. More recently, Walker et al. (1995) examined the time-course effect of a distractor appearing in left hemifield while the target appeared mirror opposite this in the right hemifield (the fixation point remained continuously present). Again, distractors presented close to target onset (and slightly thereafter) produced the greatest latency increase, but if presented more than 100 msec before the target, latencies were facilitated.

The onset of a non-target stimulus then can facilitate saccadic latency by acting as a warning signal, but it appears to require at least a 100 msec distractor-to-target lead. It is unlikely then that the maximum distractor-to-target interval employed in our paradigm (100 msec) will result in a significant warning effect with the small centrally displayed
patch of pink noise. However, given that the large patch of noise was not interpreted as a
distractor in Exp. 2, it might provide a reasonable warning signal. In addition, as the
change-event begins to occur after target onset (at target SOAs < 0), we were interested
in whether the large patch change-event would begin to interfere with the saccade.

Results and Discussion

Accuracy. Figures 5A and B show the mean signed and unsigned error,
respectively, along the target axis for each condition. As with the previous two
experiments, there were no obvious differences between conditions in terms of accuracy,
except for a possible increase in saccadic undershooting, and increased unsigned error, in
the large noise patch condition as target SOA increased above 0msec. We ran a repeated
measures ANOVA on the mean unsigned error for the large patch condition only, across
target SOAs. The test was significant, $F(4,16) = 5.85, p < .01$, suggesting at least some
decrease in accuracy to targets in the background of pink noise as the gap between patch
onset and target onset increased (though post hoc tests were not significant). It could be
argued that some local regions of the large texture of pink noise stimulated neighboring
locations to the target causing a “global effect” (Deubel et al., 1984; Findlay, 1982).
However, the location of such a region should be random and might just as likely cause a
latency increase similar to typical remote distractors (Walker et al., 1997), which clearly
did not happen.

-Insert Figure 5 here-

Latency. Figure 5C shows mean latencies for each condition across target SOAs.
In terms of the control condition we see the expected decrease in latency as target SOA
increases from a -100msec fixation overlap to a +100msec gap. If we consider the
distractor conditions relative to this, we also see a decline in latency as SOA increases,
but there is also a noticeable interaction: Latencies in the small patch condition remain elevated relative to the control between SOAs of -100 and 0msec, whereas there is virtually no difference between the large patch condition and the control up to this point. At target SOAs greater than this the pattern begins to turn around, as latencies in the large patch condition continue to decrease, while differences between the small patch condition and the control become smaller.

Figure 5D shows the difference between control and distractor conditions across target SOA. Scores in the positive direction indicate a facilitatory effect on latency (i.e., a latency decrease), and negative scores indicate an increase in latency. Given the similarity in latency difference scores between SOA of -100 to 0msec, and between +50 and +100msec, we collapsed the data into two temporal categories (SOAs <= 0, and SOAs > 0) before running tests. We then ran a 2 x 3 (i.e., 2 target SOAs x 3 stimulus conditions) repeated measures ANOVA on the resulting mean latencies. There was a significant interaction between SOA and stimulus conditions, $F(2,8) = 34.17, p < .001$.

We were primarily interested in differences of non-target stimulus conditions relative to the no-distractor control condition, so we ran only 4 Bonferroni adjusted paired-samples t-tests to tease apart the interaction: the small patch versus control, and the large patch versus control, both at the early temporal period (SOAs <= 0), and at the later temporal period (SOAs > 0). Table 1 shows the mean latencies and difference scores for these conditions. In short, only the small patch showed an effect at the early temporal period, and only the large patch showed an effect at the later temporal period. That is, the small central patch of pink noise resulted in a significant distractor effect, but only at target SOAs of <= 0. The large patch of pink noise actually reduced latencies relative to the control condition when it was onset prior to the target. This is surprising for a number
of reasons: First, the effect of the large patch of pink noise (at SOAs >= +50) decreased latency relative to the effect of fixation gap, which is known to reduce latency itself. In addition, the small patch produced no such facilitatory effect, despite the fact that it was centrally displayed and clearly visible, as evidenced by the significant latency increase at SOAs <= 0. Furthermore, recall that the visibility of our target was reduced in the background of noise, relative to neutral gray¹. This effect is also in strong contrast to research suggesting a display change causes in an inhibited saccadic response (Reingold and Stampe, 2000, 2002).

Facilitation from the large patch may be at least partially a warning effect. Distractor stimuli have been shown to produce warning effects, but typically at earlier onsets relative to the target (gaps of > 100msec, Braun and Breitmeyer (1990); Ross and Ross, 1980; Walker et al., 1995). It is possible that since the large noise display was not interpreted as a distractor, its effect as a warning signal may have been more effective than the small patch. Nonetheless, at least part of the facilitatory effect of fixation gap is due to a warning signal (Kingstone and Klein, 1993; Reuter-Lorenz, Oonk, Barnes and Hughes, 1995), and the prior onset of the large patch of random noise in this experiment significantly reduced latency relative to this. We will discuss another possibility later related to the statistical property of pink noise.

We recognize that there is some indication of a leveling-off of the gap effect in the control condition from an SOA of 0 to +100 (Figure 5C). It could be argued that the interaction is due to this rather than the non-target stimulus conditions. However, despite the robustness of the gap effect, its size is likely to depend on the degree to which the conditions under which it is tested facilitate express saccades (Wenban-Smith and
Findlay, 1991). We believe that the reduced target predictability in our study as compared with typical gap studies explains part of this discrepancy (Schiller, Haushofer and Kendall, 2004). Had express saccades been present in our data, we suspect that the slope of both the control and non-target stimulus conditions would have been steeper during the gap interval, but the interaction would still be present. Furthermore, all trials from all conditions were randomly interleaved, so we see no systematic reason why the interaction might be more attributable to the control rather than experimental conditions. It is also important to note that there is consistently no deviation between the control and large patch condition up to an SOA = 0 msec (Figure 5C). This provides a clear indication that the large patch of noise had no effect on the mechanisms influencing saccade latency during this period. Only after an SOA > 0 do we begin to see a difference, which can only be attributable to the single difference between these two conditions: the onset of the large non-target stimulus.

**Experiment 4**

We have established that a small (2.3 x 2.3 deg) patch of pink noise can result in a significant distractor effect even if presented up to 100msec after target onset, and that the opposite effect can occur with prior onset of a larger portion (36 x 36 deg) of the same stimulus. The purpose of this experiment was to test various patch sizes between these two extremes. One limitation was that we could only increase the patch of noise up to a certain size, after which it would overlap with the least eccentric target location. Thus only patch sizes below this limit were used. Nonetheless we were able to vary the size from just below the limit of the collicular fixation zone as defined by Munoz and Wurtz (1993a), to reasonably above it. Each unit of size increase was approximately double the area of the former. Physical patch sizes were 45 x 45 pixels, 64 x 64 pixels, 90
x 90 pixels, and 128 x 128 pixels. This corresponded to visible patch sizes of approximately 1.6 x 1.6 deg, 2.3 x 2.3 deg, 3.2 x 3.2 deg and 4.5 x 4.5 deg, respectively.

We were unsure whether we would see an initial increasing distractor effect as the size of the noise patch increased, or if the effect would begin to fade immediately toward that which we found for the large portion of noise. Weber and Fischer (1994) found an increasing effect as the size of a small, square distractor increased from 0.1 x 0.1 deg to 0.2 x 0.2 deg to 0.4 x 0.4 deg (the target being also a small square of 0.2 x 0.2 deg). While these stimuli were much smaller than ours, Weber and Fischer’s data do indicate that the effect is particularly sensitive to small changes in size.

Since the effect of remote distractors decreases with eccentricity (Walker et al., 1997), it could be argued that an effect of distractor size in this experiment is the result of the high-contrast edges stimulating increasingly eccentric locations along the presumed fixation zone, rather than the surface area of the patch itself. Thus, we included additional data from 4 of our subjects on a control experiment using edge-filtered patches. These patches were generated by gradually, eccentrically reducing contrast at the edges to 0% at a rate of approximately 3.3% per pixel over 30 pixels (~1 deg). Visibly, the edge-filtered patches were designed to be nearly identical in size to the originals. The data from this experiment are included within the same plots.

Results and Discussion

Accuracy. Figures 6A and B show the mean signed and unsigned error, respectively, along the target axis for each condition. The gray circles with dotted lines represent the data of the 4 subjects that also completed the edge-filtered control experiment. What is immediately obvious is the overall greater amount of over-shooting (signed error, Figure 6A) in the edge-filtered experiment. Since this was also true
between the no-distractor control conditions of the original and edge-filtered experiment (which were essentially identical in design), we attribute the difference to factors outside our experimental manipulation. More importantly, there were no significant differences in accuracy between distractor and no-distractor conditions for either the original experiment (signed error, $F(4,16) = 1.70, p = .20$; unsigned error, $F(4,16) = 1.44, p = .27$), or the edge-filtered experiment (signed error, $F(4,12) = 1.46, p = .54$; unsigned error, $F(4,12) = 1.02, p = .43$). Thus, saccadic accuracy was again not significantly affected by the presence of our non-target stimuli.

-Insert Figure 6 here-

Latency. Figure 6C shows the mean latency for each of the conditions. Figure 6D shows the size of the effect. The edge-filtered control experiment is represented by the open circles with the dotted line. As can be seen, latencies showed a steady decrease as the size of the central pink noise distractor increased, and the same is true for the edge-filtered control experiment. A repeated measures ANOVA revealed a significant effect of patch size, $F(3,12) = 5.31, p < .05$ (original experiment), and $F(3,9) = 8.15, p < .01$ (edge-filtered experiment).

The results of Experiment 4 give us a sense of the degree to which the distractor effect is modified by changes in distractor size. Since the same result was obtained in the edge-filtered control experiment, it is unlikely that the effect was due to the high-contrast edges stimulating increasingly eccentric locations of an extended fixation zone. The effect is therefore more likely related to the overall surface area of the patches. One possibility is that modification of the non-target size is related to the degree to which it is interpreted by the visual system as a salient element in the visual field. Whether this is based on some absolute size or relative to the target size would require further testing.
Physiologically, this effect might also be due to the possibility that the smaller patch is simply better at driving fixation mechanisms. Nonetheless, this experiment again brings into question the proposed nature of the mechanisms underlying increased saccadic latency due to the appearance of non-target stimuli.

**General Discussion**

In sum, the experiments presented here supported our predictions: We demonstrated that the remote distractor effect is possible with a small patch of pink noise as a distractor (Exp. 1). More importantly we confirmed that raw visual stimulation of the central region representing the collicular fixation zone is not in itself sufficient to produce a significant increase in saccadic latency to a simultaneously presented target (Exp. 2). This may have been implied from McPeek and Schiller’s (1994) study, but to the best of our knowledge no one has made this distinction or put it to a direct test. Recall that McPeek and Schiller showed that the numerosity of non-target elements in a pop-out display affects whether or not express saccades are possible (i.e., only a background of very densely packed non-target stimuli permitted express saccades). Presumably densely packed non-target stimuli permit rapid oculomotor target selection because there are no distinct elements that the visual system might interpret as a distractor. It is possible that the large (36 x 36 deg) non-target display of pink noise in the present study did not increase latency for the same reason.

Physiologically, it is possible that the display-sized non-target stimulus employed here was simply not adequate to drive the cells responsible for visual fixation. It is also unlikely that local regions of this random noise texture activated other sub-populations of saccade-related collicular neurons, which might have subsequently increased latency through lateral inhibitory interactions (Munoz and Istvan, 1998; Olivier et al., 1999). It is
questionable then whether a background change without the presence of obviously salient elements should drive fixation- or saccade-related collicular cells. Recall that Reingold and Stampe (2000, 2002) reported an inhibited saccadic response as a result of a flashed display change (e.g., a homogenous blank field). This inhibitory effect was shown to occur as early as 60 msec from the onset of the flashed event, so Reingold and Stampe implicated the SC as the only possible substrate behind the effect because it can receive direct visual input in as little as 35 msec (Rizzolatti, Buchtel, Camarda, and Scandolara, 1980). In essence, they argue that either the onset of the display stimulated competing sub-populations of build-up neurons, which through lateral inhibition might have delayed a saccadic response (Munoz and Istvan, 1998), or the display change stimulated an extended fixate system (Walker et al., 1997). Similarly, Baccino et al. (2001) interpreted the effect of a background flicker on saccadic latency as “an area of remote distractors that inhibit, i.e. produce longer latencies in simple horizontal saccades”, in reference to Walker et al. (1997).

What then might account for the difference between our data and the saccadic inhibition effect reported by Reingold and Stampe? Unfortunately it is not possible to adequately answer this question without further research. We know however that the difference is not likely due to a luminance change between the original- and change-display. Both target and non-target stimuli in our experiments had the same average luminance (32 cd/m²), and the effect reported by Reingold and Stampe (2000) has been shown with an original- and change-display of equal luminance. While the change in Reingold and Stampe’s paradigm is only flashed for 33 msec (while ours remained present once onset), we suspect that this also cannot account for the difference.
In addition, we have shown that the prior onset of the display-sized pink noise texture (Exp. 3) can reduce latencies relative to a neutral gray control condition, and this effect occurs at a shorter non-target to target gap (<= 100msec) than is typically found with distractors as warning signals (> 100msec, Braun and Breitmeyer (1990); Ross and Ross, 1980; Walker et al., 1995). We suggested that the onset of this large texture might have provided a more effective warning signal because it was not simultaneously interpreted as a distractor like the small patch. Nonetheless, at least part of the effect of fixation offset is assumed to be due to a warning signal (Kingstone and Klein, 1993; Reuter-Lorenz et al., 1995), and mean latency in our large noise-patch condition was significantly reduced relative to this.

Another possibility alluded to earlier is that the structure of a pink noise texture has some special properties that might permit rapid saccade target selection. For example, there is evidence that the visual system is optimized for the second-order (i.e., Fourier) composition of natural images in general (Párraga, Troscianko and Tolhurst, 2000), and for detecting animals in such images (Thorpe, Gegenfurtner, Fabre-Thorpe and Bülthoff, 2001). Saccadic target selection may also be optimized for the second-order image properties of pink noise given its similarity to natural images in this regard. Examination of such low-level image attributes on saccadic performance is an intriguing area for further testing.

Finally, we have shown the degree to which manipulations in the size of the central distractor can significantly affect saccadic latency (Exp. 4). Each unit of increase, in which the patch doubled in size, was accompanied by a steady decrease in latency. This effect was nearly identical when we filtered out the high-contrast edges of the patches, so it is unlikely to be due to such edges stimulating increasingly eccentric
locations along an extended fixation zone (Walker et al., 1997). We proposed that as the size of the texture increased it was no longer interpreted by the visual system as a salient element (e.g., a figure or an object) in the visual field. Another possibility mentioned earlier, though perhaps not mutually exclusive from the previous suggestion, is that as patch size increased, its ability to drive collicular fixation neurons decreased. This is not necessarily inconsistent with an extended fixate system. Findlay and Walker (1999) have noted that their idea of such a system was not meant to imply that the receptive fields of fixation neurons extended 10 deg, only that the distributed network of these cells might extend to this extreme. Our results do support the idea that the foveal region is particularly sensitive to non-target stimulation, provided the stimulus is small enough to act as a fixation target. What is less clear is whether the effect for peripheral distractors reflects an extended fixation region, or if such a result is better explained by the competitive interaction mechanism suggested by Olivier et al. (1999). We believe our results, in particular the lack of a target x distractor interaction in Exp. 1, suggest the latter explanation.

We realize that we have limited this discussion to the SC at the expense of oversimplification. It has been known for some time that the SC receives signals from various cortical areas (e.g., frontal eye fields, Segraves and Goldberg, 1987; lateral intraparietal area, Lynch et al., 1985). It is also believed that the SC is an important structure for integrating these signals (Trappenberg et al., 2001) before sending a final message to the saccade generating circuitry in the brainstem, but it is beyond the scope of this paper to speculate on how these signals might contribute to the effects reported here. Our emphasis on the SC was purely motivated by its presumed role in the remote distractor effect (Findlay and Walker, 1999; Olivier et al., 1999; Trappenberg et al., 2001;
Walker et al., 1997), and other inhibitory effects on saccadic programming (Baccino et al., 2001; Reingold and Stampe, 2000, 2002). The series of experiments reported here should provoke more questions as to the nature of the mechanisms believed to underlie the effect of non-target stimuli on a saccadic response.

Our results might also have implications for higher level figure-ground processes on saccadic eye movements. In particular, it brings up the interesting question of whether neurons in the fixation region of the SC already possess the capability of distinguishing figure from ground, or if such processing is only mediated by cortical areas (e.g. V1, Lamme, 1995). Further research is needed to explore this intriguing question.
Footnotes

1 Thresholds to the stationary target Gabor in pink noise versus the neutral gray background were determined for observer BW using a staircase procedure. Both conditions with the various target eccentricities were randomly interleaved. Fixation was maintained with the aid of a central point which remained visible throughout each trial. The target appeared randomly 4, 7 or 10 deg left or right of fixation. After each trial the observer was prompted to respond on a game pad whether the target appeared left or right, and then at which eccentricity, “near”, “medium” or “distant”. Thresholds were calculated by taking the average contrast of a small sample of trials during the final reversals. This is similar to a suggested method by Macmillan and Creelman (1991) for staircase procedures, and provided reasonable thresholds for our purpose. Resulting thresholds for BW for targets 4, 7 and 10 deg respectively were 2.9%, 3.9% and 5% contrast against a neutral gray background, and 5.9%, 7.7% and 7.2% contrast when the target was embedded in the noise. Target visibility was reduced in the noise.

2 We recognize the distinction between comparing proportions of express saccades with mean latencies. With the exception of Experiment 3, we did not employ a gap paradigm. As such, there was no indication of bimodality in our data, so we focused on mean latencies instead of proportions of express saccades. Nonetheless, variations in proportions of express saccades would also likely influence average latencies in a consistent manner, and both dependent measures have been shown to be reasonable indicators of a distractor effect, which was the primary issue.
Acknowledgements

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References


reaction times of goal directed eye movements. *Experimental Brain Research, 57, 191-
195.

characteristics of superior colliculus neurons antidromically activated from the
omnipause region in monkey. *Journal of Neurophysiology, 78, 2221-2225.

Kingstone, A. & Klein, R. M. (1993) Visual offsets facilitate saccadic latency:
does predisengagement of visuospatial attention mediate this gap effect? *Journal of
Experimental Psychology: Human Perception and Performance, 19, 1251-1265.


Lamme, V. A. (1995) The neurophysiology of figure-ground segregation in

Lévy-Schoen, A. (1969) Determination et latence de la response oculomotrice a

of two cytoarchitectonic subregions of the inferior parietal lobule of macaque upon the
deep layers of the superior colliculus. *Journal of Comparative Neurology, 235, 241-254.

New York: Cambridge University Press.

on the latency of saccadic eye movements of the rhesus monkey. *Vision Research, 34,
2293-2305.


Figure Captions

Figure 1. (A) Sample of a small central patch of pink noise as a distractor, with a Gabor-target ~10 deg to the right. (B) Sample of a 36 x 36 deg (1024 x 1024 pixels) patch of noise with an embedded target at ~10 deg to the right. Both target and non-target stimuli were presented at 50% contrast, with the same average luminance as the neutral gray background at 32 cd/m². Note that actual stimulus contrast and sizes were not exactly as shown here (for demonstration only).

Figure 2. The sequence of events on a given trial. Except for exp. 3 (time-course of target onset), all events occurred simultaneously (1000msec after trial initiation). In exp. 3, target onset was varied relative to the remaining events. Thus when the non-target stimulus was absent, the result was a fixation gap/overlap paradigm, which served as the control condition.

Figure 3. (A) Mean signed error, and (B) unsigned error along the target axis as a function of distractor eccentricity. (C) The thick, solid line represents mean saccade latency as a function of distractor eccentricity (target eccentricities combined). Errorbars represent 1 standard error. Standard error for the control condition (solid line) is represented by the shaded gray area. The three thin lines represent mean saccade latency for each target eccentricity separately. The 4, 7 and 10 deg targets are represented by the thin dotted, dashed, and solid line, respectively. (D) The difference values represent the mean latency of each distractor condition minus the mean latency of the control condition (target eccentricities combined).

Figure 4. (A) Mean signed error, and (B) unsigned error along the target axis as a function of pink noise patch size. (C) Mean latency as a function of patch size. Errorbars represent 1 standard error. Standard error for the control condition (solid line) is
represented by the shaded gray area. (D) The difference values represent the mean latency of the noise patch condition minus the mean latency of the control condition.

**Figure 5.** (A) Mean signed error, and (B) mean unsigned error along the target axis as a function of distractor condition and target SOA. (C) Mean latency as a function of distractor condition and target SOA. Errorbars represent 1 standard error. (D) The difference values represent the mean latency of the control condition minus the mean latency of the distractor condition for each target SOA. Positive scores represent a facilitatory effect (i.e., latency decrease) relative to gap (target SOAs > 0) and overlap (target SOAs < 0) control conditions. Negative scores represent increased latency with respect to the control conditions.

**Figure 6.** (A) Mean signed error, and (B) unsigned error along the target axis as a function of size of central distractor patch. Gray circles with dotted lines represent the edge-filtered control experiment. The no-distractor control condition of this experiment is represented by the flat dotted line. (C) Mean latency as a function of the size of central distractor. Errorbars represent 1 standard error. Standard error for the no-distractor control conditions represented by the shaded black region on the left (primary experiment), and the shaded gray region on the right (edge-filtered experiment). (D) The difference values represent the mean latency of the noise patch condition minus the mean latency of the control condition. Note that each increase in patch size represents approximately twice the area of the former (e.g., $1.6^2$, $2.3^2$, $3.2^2$ and $4.5^2 = 2.6$, $5.3$, $10.2$ and $20.3$, respectively).
Table 1. Mean latencies and difference scores for non-target stimulus conditions relative to no-distractor control condition as a function of SOA (Experiment 3).

<table>
<thead>
<tr>
<th>Condition</th>
<th>SOA &lt;= 0</th>
<th>SOA &gt; 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-distractor control</td>
<td>$M = 236, SE = 9.9$</td>
<td>$M = 186, SE = 12.2$</td>
</tr>
<tr>
<td>2.3 x 2.3 deg patch</td>
<td>$M = 272, SE = 5.3$</td>
<td>$M = 192, SE = 11.3$</td>
</tr>
<tr>
<td>36 x 36 deg patch</td>
<td>$M = 239, SE = 6.6$</td>
<td>$M = 166, SE = 9.8$</td>
</tr>
<tr>
<td>Control – small patch</td>
<td>$M$ diff = -36*, $SE = 4.9$</td>
<td>$M$ diff = -6, $SE = 3.1$</td>
</tr>
<tr>
<td>Control – large patch</td>
<td>$M$ diff = 3, $SE = 4.1$</td>
<td>$M$ diff = 20*, $SE = 4.1$</td>
</tr>
</tbody>
</table>

*p < .01 (with Bonferroni adjustment)
Figure 1.
Figure 2.

**Exp. 1, 2 and 4:**

- Fixation
- Non-target stimulus
- Target

**Exp. 3 (varied target onset):**

- Fixation
- Non-target stimulus
- Target

Overlap | Gap
Figure 4.
Figure 5.
Figure 6.