



Influence of target and distractor contrast on the remote distractor effect

Sabine Born*, Dirk Kerzel

Faculté de Psychologie et des Sciences de l'Éducation, Université de Genève, 40 Boulevard du Pont d'Arve, 1205 Genève, Switzerland

ARTICLE INFO

Article history:

Received 4 March 2008

Received in revised form 4 September 2008

Keywords:

Eye movement

Distractor

Saccade

Latency

Contrast

ABSTRACT

In the absence of distractors, saccadic latencies are influenced by target characteristics such as contrast. The same characteristics were expected to influence the remote distractor effect (RDE) when varied in the distractor. We conducted three experiments in which we varied target and distractor contrast orthogonally. The results show that the RDE is not so much modulated by distractor contrast per se. Rather it strongly depended on the overall saccadic latencies afforded by the target: typically, shorter latencies resulted in stronger RDEs. We argue that average saccadic latencies to a target determine whether distractor-related activity temporally coincides with target-related activity. The temporal overlap is necessary for the respective neuronal signals to inhibit each other, thus evoking the RDE.

© 2008 Elsevier Ltd. All rights reserved.

1. Introduction

Visual events occurring simultaneously with the onset of a saccade target can have an impact on saccadic latency. Lévy-Schoen (1969) was probably the first to describe the phenomenon of prolonged latencies when two potential target stimuli were presented simultaneously in opposite hemifields (bilaterally), compared to a condition in which both were presented in the same hemifield (ipsilaterally). She argued that the additional decision process of having to select the direction of the eye movement with bilateral stimuli can account for the delay in saccade initiation. Two more recent studies conducted by Walker and colleagues (Walker, Deubel, Schneider, & Findlay, 1997; Walker, Kentridge, & Findlay, 1995) found similar prolonged saccadic latency for bilateral compared to unilateral stimulation (only one target). Moreover, they showed that the additional decision process with bilateral stimulation does not explain the delay as it was still present when the saccade target direction was held constant, thus designating one stimulus unequivocally as target and the other as a distractor (Walker et al., 1995; see also Benson, 2008). They also demonstrated that central and even ipsilateral distractors can produce a similar increase in saccadic latency, provided the angular distance between target and distractor exceeds 10° (Walker et al., 1997). Therefore, the effect is referred to as the remote distractor effect (RDE). The basic finding in the RDE, that is an increase of saccadic latency when a distractor is presented simultaneously with a visual saccade target compared to trials without distractor, has been replicated in numerous studies (Adler, Bala, & Krauzlis, 2002; Griffiths, Whittle, & Buckley, 2006; Honda, 2005; Ludwig, Gilchrist, &

McSorley, 2005; McSorley & Findlay, 2003; Sumner, Adamjee, & Mollon, 2002; Walker, Maurer, Pambakian, & Kennard, 2000; Walker et al., 1995, 1997; White, Gegenfurtner, & Kerzel, 2005).

1.1. Models of the RDE

Various models of saccade generation that incorporate the RDE assume a retinotopically organized saccade map in which incoming visual stimulation results in the rise of neuronal activity at the corresponding location in the map (e.g. Findlay & Walker, 1999; Godijn & Theeuwes, 2002; Kopecz, 1995; Trappenberg, Dorris, Munoz, & Klein, 2001). In most models, a saccade is initiated as soon as this local activity peak reaches a critical threshold (Godijn & Theeuwes, 2002; Kopecz, 1995; Trappenberg et al., 2001). If two stimuli, target and distractor, appear simultaneously in the visual field, activity will rise at two locations and target- and distractor-related activity enter a race to threshold. This race is not independent. The two activated sites inhibit each other so that it takes longer for one of the two to reach the threshold for saccade initiation. Consequently, saccadic latency is prolonged compared to a single target condition (Godijn & Theeuwes, 2002; Kopecz, 1995; Trappenberg et al., 2001).

Findlay and Walker (1999) propose a slightly different framework. Their saccade map is not homogenous but consists of a *fixate centre* and a functionally opposed *move centre* that interact in a push–pull-fashion. Central visual events have only a direct influence on the *fixate centre* whereas events in the near periphery (up to 10° of visual angle) influence both the *move centre* as well as the *fixate centre*. A saccade is initiated when activity in the *fixate centre* falls below a critical threshold. According to this model, the onset of a visual target stimulus shifts the balance between the two opposed centres towards the *move centre*. Via inhibitory

* Corresponding author. Fax: +41 (0) 22 37 99 229.

E-mail address: sabine.born@unige.ch (S. Born).

connections, activity in the *fixate centre* is reduced until the threshold for saccade generation is reached. In contrast, visual distractors prolong saccadic latencies by activating the *fixate centre*. Hence it takes longer for the activity in the *fixate centre* to fall below threshold. Although this framework is slightly different from the others, all models share the key assumptions that target and distractor activate different neuronal populations that inhibit each other and that saccade initiation is delayed until a threshold is reached.

Given these key assumptions, the models offer several possibilities of how stimulus characteristics might influence the corresponding neuronal activity. For instance, stimulus properties might determine the speed at which the corresponding activity rises in the saccade map, they might influence the peak activity that is reached or the latency of the neuronal response (i.e. the time between stimulus onset and the corresponding neuronal activity in the saccade map). In either case, a reasonable assumption is that for target properties that produce short saccadic latencies, one or more of these aspects of the neuronal response will be enhanced. For these “efficient” targets, a distractor might be less disruptive than for targets that produce a weaker or slower neuronal response. In contrast, if the same property is present in the distractor, the distractor-related neuronal response should be enhanced and the disruptive effect should increase. Hence, the same properties that would reduce the RDE when present in the target should increase the RDE when present in the distractor.

1.2. Distractor properties influencing the remote distractor effect

To our knowledge, the only study that systematically varied target and distractor properties simultaneously was conducted by Ludwig et al. (2005). They investigated the effect of spatial frequency on the remote distractor effect using Gabor patches. Their results roughly match our assumptions. Targets of low spatial frequency (2 cycles per degree, cpd) produced shorter saccadic latencies than targets of high spatial frequency (8 cpd), designating low spatial frequency as a stimulus property enhancing the neuronal response (see also Ludwig, Gilchrist, & McSorley, 2004). The RDE indeed decreased for low compared to high spatial frequency targets, albeit only for distractors of high spatial frequency. Moreover, the RDE increased with low spatial frequency of the distractor, albeit only in the condition with low spatial frequency targets. Hence, instead of the expected main effects of target and distractor spatial frequency, they found an interaction.

Comparisons between studies support the idea that effects of distractor properties on the RDE can be inferred by the effects of target characteristics on saccadic latencies. Concerning stimulus size, Perron and Hallett (1995) found saccadic latencies to be speeded up with increasing target size for targets varying between 0.8° and 2.3° in diameter, designating larger targets as more efficient in this size range. Accordingly, a study by Vitu, Lancelin, Jean, and Farioli (2006) found saccadic latency to increase with increasing distractor length for central distractors (strings of letters) that extended between 0.31° and 2.79° into the ipsilateral field. The effect levelled off somewhat beyond 1.24–1.55° (4–5 letters). Although no control condition without distractor was included in their study, these results would correspond to an increasing RDE with increasing distractor size, confirming that large stimuli (in this range) are not only efficient targets, but also efficient distractors. For larger stimuli, Ploner, Ostendorf, and Dick (2004) reported longer saccadic latencies for targets increasing in size from 1° to 10°. Conversely, White et al. (2005) found a steady decrease of the RDE for increasing size of centrally presented distractors subtending 1.6°–4.5° of visual angle and no RDE at all with a change of the entire background simultaneous to target onset.

Why would behaviour be so different for smaller compared to larger stimuli? For small stimuli (up to ~1.5°) in the fovea, it was

assumed that increases in size increases the activity of fixation neurons (Vitu et al., 2006). In contrast, when foveal distractors extend further into the periphery, their ability to drive fixation-related neurons might level off or even decrease with increasing size (Vitu et al., 2006; White et al., 2005). Alternatively, in uniform saccade map models, it is widely assumed that activity in the saccade map spreads to nearby locations and that only distant locations are inhibited (e.g. Godijn & Theeuwes, 2002; Trappenberg et al., 2001). Thus, for targets or distractors that are smaller than their own excitatory range, activity in the map might increase with increasing stimulus size. However, as soon as the boundaries of the stimulus extend into its own inhibitory range, it might somehow inhibit itself, resulting in a less efficient target or distractor.

1.3. Aim of the current study

In sum, there is tentative evidence that effects of target properties on saccadic latencies are predictive of effects of distractor properties on the RDE. However, only one study varied target and distractor properties simultaneously (Ludwig et al., 2005). To fill this void, we varied target and distractor contrast orthogonally in a remote distractor paradigm. In the absence of distractors, saccades were found to be faster to high-contrast than to low-contrast targets (Doma & Hallett, 1988a,b; Ludwig et al., 2004; White, Kerzel, & Gegenfurtner, 2006). Therefore, we expect that these efficient, high-contrast targets reduce the impact of simultaneously presented distractors compared to low-contrast targets. If, on the other hand, a distractor is presented at high contrast, the RDE should be stronger than with low-contrast distractors. These assumptions are based on the notion that competition between target- and distractor-related activity modulates the RDE (Findlay & Walker, 1999; Godijn & Theeuwes, 2002; Kopecz, 1995; Trappenberg et al., 2001). Thus, our approach tests a key assumption of the prevalent models of the RDE and our results might help to complement and refine these ideas.

2. General methods

2.1. Stimuli

The central fixation stimulus consisted of a horizontal black line of 3×1 pixels ($0.10^\circ \times 0.03^\circ$) on a grey background. Targets and distractors were vertically oriented stationary Gabor patches with a spatial frequency of 4 cpd and had the same average luminance as the grey background on which they were displayed (66 cd/m²). The crucial manipulation in the different experiments was the orthogonal variation of target and distractor contrast. The specific stimulus parameters are reported in the introductory sections of each experiment and summarized in Table 1. Contrast was defined as the Michelson contrast (expressed in percentage values: $(L_{\max} - L_{\min}) / (L_{\max} + L_{\min}) * 100\%$) of the underlying sinusoid. Gaussian standard deviations of the Gabors varied between 0.25° for the highest contrast condition and 0.34° for the lowest contrast condition in Experiment 1¹ and were held constant at 0.42° in Experiments 2 and 3.

¹ As the perceived size of a Gabor varies with its contrast, we tried to adjust the Gaussian standard deviation of the Gabors according to an equation that we derived from Fredericksen, Bex, and Verstraten (1997, Eq. (3)). In subsequent experimental work (not reported here) we noticed that the main patterns in the results were not consistently affected by the variations in physical size introduced by this correction. In addition, it was not clear whether the expression adopted to correct for perceived size differences was applicable in the current paradigm. We therefore decided to drop the perceived size correction in Experiments 2 and 3. Fig. 1 shows the stimuli for all three experiments. As adjustments were minimal, we do not believe that they affected the results of Experiment 1.

Table 1
Stimulus parameters in the different experiments

| Exp. | Stimulus | Contrast ^a | Eccentricity ^b | Prop. nd ^c |
|------|------------|--|---------------------------|-----------------------|
| 1 | Target | 10, (18), ^d 32, (56), ^d 100 (%) | 10° | 0.25 |
| | Distractor | 10, 18, 32, 56, 100 (%) | 0° | |
| 2 | Target | 1.1, (2), ^d 4, (8), ^d 16 (× CDT) | 10° | 0.25 |
| | Distractor | 1.1, 2, 4, 8, 16 (× CDT) | 0° | |
| 3 | Target | 10, (18), ^d 32, (56), ^d 100 (%) | 5, 10° | 0.25 |
| | Distractor | 10, 18, 32, 56, 100 (%) | 5, 10° | |

^a Michelson contrast: $(L_{\max} - L_{\min}) / (L_{\max} + L_{\min}) * 100\%$; partly expressed as multiples of contrast detection threshold (CDT).

^b Horizontal eccentricity in degree of visual angle.

^c Proportion of no distractor control trials in the experiment.

^d Only in the no distractor control condition.

2.2. Equipment

Stimuli were generated using a ViSaGe graphics card (Cambridge Research Systems Ltd., Rochester, UK) and displayed on a 21" CRT monitor (Mitsubishi Diamond Pro 2070SB) running at 100 Hz. The screen's resolution was set to 1024 × 768 pixels, which corresponded to physical dimensions of 39 cm wide × 29.2 cm high. At a viewing distance of 67 cm, the display occupied a retinal area of 33° horizontally and 25° vertically. About 31 pixels were displayed per degree of visual angle. Eye movements were recorded using a CRS High Speed Video Eyetracker (Cambridge Research Systems Ltd., Rochester, UK) at a sample rate of 250 Hz. The subject's head was stabilised by a chin and a forehead rest.

2.3. Procedure

At the beginning of each trial observers fixated the central fixation line. After a random delay of 500–1200 ms a target Gabor appeared to the left or right. The subjects' task was to execute a saccade to the centre of this target patch, as soon as it appeared. They were instructed that speed as well as accuracy was important, though the emphasis lay on speed. On 75% of trials a distractor stimulus was presented. Distractors always appeared simultaneously with targets either centrally (Experiments 1 and 2, target direction at random) or peripherally in the opposite hemifield (Experiment 3, target direction blocked) and observers were asked to ignore them. After saccading to the target, participants returned their gaze to the centre to await the next target stimulus. Trials were initiated automatically after an intertrial-interval of ~1 s, no specific action (e.g. button press) of the observer was required. The sequence of events is illustrated in Fig. 1.

2.4. Analyses

Eye movement data were analysed off-line. A time window of 250 ms before and 800 ms after target onset was specified for analysis in each trial. Saccade onsets were detected using a velocity criterion of 30°/s. Only the first saccade in the time window with an amplitude >1° was considered. Trials were excluded if (1) no saccade was found within the time window, (2) saccades were executed into the wrong direction, (3) saccades were anticipatory (latency < 80 ms), (4) gaze deviated by more than 1.5° from the display centre at the time of saccade onset (5) saccadic landing position (horizontal gaze coordinate of the first sample with a velocity <30°) deviated more than 3° from the centre of targets presented at 10° (Experiments 1–3) or 1.5° from the centre of targets presented at 5° (Experiment 3) or (6) the eye tracker lost track between the beginning of the time window and the end of the saccade (e.g. as a result of a blink). The complete data set of a subject was discarded when less than 70% of the trials were valid.

Median saccadic latencies in the various distractor and no distractor control conditions were computed for every subject. The

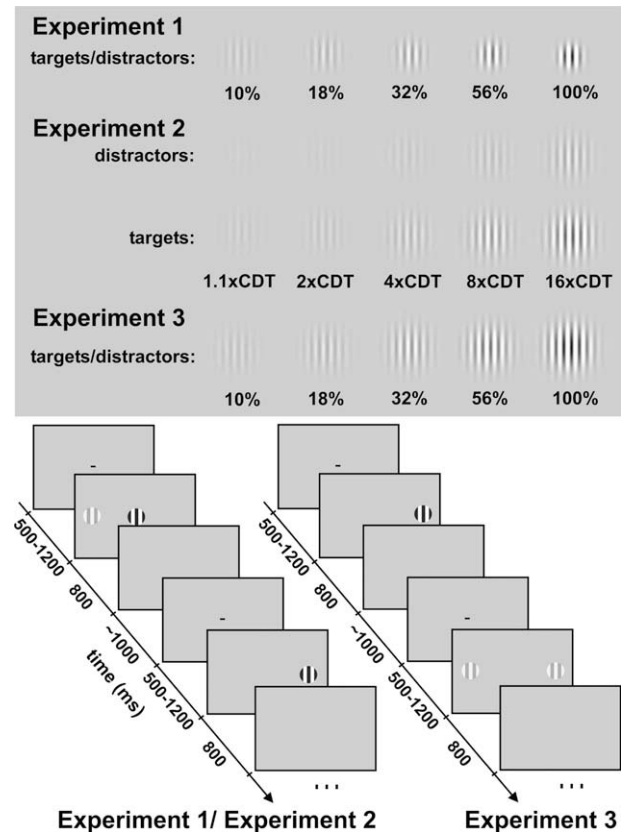


Fig. 1. Stimuli and stimulus sequence in Experiments 1–3. Stimulus contrasts for Experiment 2 are based on CDT of a typical subject. At the beginning of each trial, subjects fixated a small fixation line. After 500–1200 ms the fixation line disappeared and a target Gabor appeared to the left or to the right (target direction was blocked in Experiment 3 and random in Experiments 1–2). Subjects were instructed to execute a saccade to the centre of the target patch. On 75% of the trials a distractor stimulus was presented simultaneously with the target (foveally in Experiments 1–2, contralateral to the target in Experiment 3). Participants were asked to ignore the distractor. After 800 ms, the target screen was followed by a blank screen that was displayed for ~1000 ms, then the next trial was initiated. Distractor and no distractor control conditions as well as target and distractor contrast conditions were randomly interleaved and equally distributed across blocks.

RDEs were calculated by subtracting the median value of the no distractor control condition from the corresponding distractor conditions. We also analysed horizontal error, defined as the difference between the saccadic landing position and the target's centre. The results partly mirrored the RDE findings. That is, a prolongation of saccadic reaction time did sometimes go along with a smaller horizontal error. However, the question whether the visual system can make use of the RDE, that is the additional time before saccade initiation, to produce more accurate saccades was not of primary concern in the current experiments. Hence, we decided not to report saccade

metrics in the present paper (see also Adler et al., 2002; Honda, 2005; Ludwig et al., 2005; Sumner et al., 2002; Walker et al., 1995, 2000, who did not report data on saccade metrics, either).

3. Experiment 1

In the first experiment, we examined how the contrast of peripheral targets and central distractors influences saccadic latency and the RDE.

3.1. Methods

Five graduate students and five first-year psychology students at the University of Geneva took part in Experiment 1. All subjects had normal or corrected to normal vision and ranged from 18 to 36 years of age. Students received course credit for their participation. Distractors were displayed centrally at five different contrasts along a logarithmic scale: 10%, 18%, 32%, 56% and 100%. Targets were presented at an eccentricity of 10° on the left or right. Target direction was randomized. In no distractor control trials, target contrast was varied in the same way as distractor contrast, resulting in target contrasts of 10%, 18%, 32%, 56% and 100%. In distractor trials, only three different target contrasts were presented: 10%, 32% and 100%. The standard deviation of the Gaussian varied between 0.25° for the 100% contrast stimuli and 0.34° for the 10% contrast stimuli.¹ The experiment was run in two sessions of approximately 45 min on separate days. Each session consisted of 5 blocks of 160 trials, resulting in 40 trials for each experimental condition. The experiment followed a repeated-measures design. All conditions were presented in a random order and equally distributed across blocks.

3.2. Results and discussion

Data of two subjects were excluded from analysis due to high percentages of invalid trials (63.2% and 37.1%, respectively). These were mostly the result of calibration difficulties. For the remaining eight subjects, 8.1% of all trials were discarded from analysis. Saccadic landing position errors (3.9%), direction errors (2.1%) and blinks (2.0%) were the most frequent errors. Fig. 5A illustrates the saccadic landing positions in Experiment 1. Included are valid trials and trials that were invalid because of a horizontal landing position error. The distribution peak falls slightly short of the target centre and landing position errors were almost exclusively undershoots.

3.2.1. Saccadic latencies

Fig. 2 summarizes saccadic latency in the no distractor control conditions of all experiments pooled over target direction. Saccadic latencies decreased with increasing target contrast. A subsequent 2 (target direction) \times 5 (target contrast) repeated-measures ANOVA confirmed a significant main effect of target contrast in Experiment 1, $F(4,28) = 95.36$, $p < .001$. Thus, the findings of previous studies (Ludwig et al., 2004; White et al., 2006) could be replicated. No further effect reached significance.

3.2.2. Remote distractor effect

We subjected the RDEs to a 2 (target direction) \times 3 (target contrast) \times 5 (distractor contrast) repeated-measures ANOVA. Fig. 3A–C shows saccadic latencies for the distractor and no distractor control conditions in Experiment 1. The RDEs can be estimated by looking at the difference between the distractor conditions and the no distractor baseline. Error bars represent the 95% confidence interval of the RDE. Thus, RDEs are significantly different from zero if error bars do not cross the baseline. Data in the figure are collapsed over target direction. Contrary to our expectations, the perturbing effect of the distractor was largely

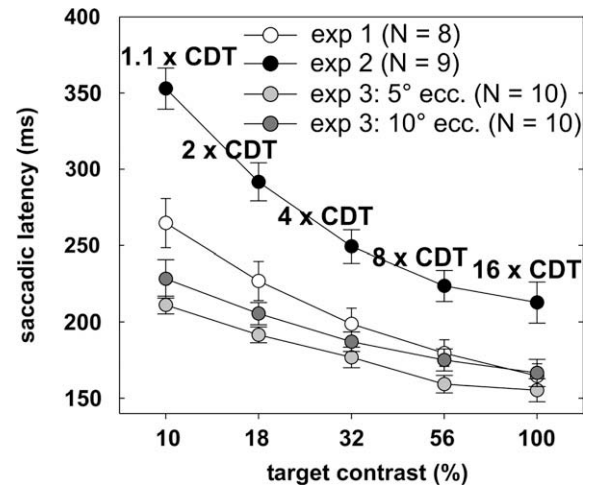


Fig. 2. Saccadic latencies as a function of target contrast in the no distractor control trials of Experiments 1–3. Target contrast in Experiments 1 and 3 was varied in terms of absolute contrast as specified on the abscissa. Target contrast in Experiment 2 was manipulated in terms of multiples of contrast detection threshold (CDT; see specifications at the corresponding data points). Error bars represent between-subject standard error.

unaffected by distractor contrast. If anything, Fig. 3A–C shows a slight decrease in the RDE with increasing distractor contrast, which was confirmed by a significant main effect of distractor contrast in the ANOVA, $F(4,28) = 4.05$, $p = .010$. Further, the main effect of target contrast was highly significant, $F(2,14) = 18.34$, $p < .001$. When target contrast was low (10%), latencies in the distractor trials were slightly faster than in the no distractor control trials (i.e. a reversed RDE). However, this slight facilitation was not significantly different from zero in any of the five distractor contrast conditions (see Fig. 3A). The 32% and 100% target contrast conditions exhibited a regular RDE that was larger with 100% than with 32% target contrast. The main effect of target direction also reached significance, $F(1,7) = 5.93$, $p = .045$. The remote distractor effect was larger for leftward than for rightward saccades (16 vs. 7 ms, respectively). As this main effect was not replicated in Experiments 2 and 3, we will not discuss it any further. A Table comparing the RDE values for left and right saccades is enclosed in Appendix A.

A possible reason for the weak modulation of the RDE by distractor contrast may have been a ceiling effect: a distractor at 10% contrast might have been sufficient to produce a maximum RDE. As we supposed that the influence of target properties on saccadic latencies is predictive of the influence of distractor properties on the RDE, saccadic latencies should likewise not diminish any further by target contrasts higher than 10%. As can be seen in Fig. 2, saccadic latencies decreased notably with increasing target contrast. An explanation for this discrepancy might be that distractors were presented centrally and targets peripherally. The contrast detection thresholds (CDTs) of central and peripheral stimuli differ substantially. Expressing the absolute contrast values used in our experiment in terms of multiples of the approximate CDT (obtained in a pilot study) yielded subjective target contrasts of ~ 2 – $20 \times$ CDT and subjective distractor contrasts of ~ 10 – $100 \times$ CDT. Thus, as saccadic latencies varied for targets presented between 2 and $20 \times$ CDT, it might still be possible that a stronger relation between distractor contrast and the RDE emerged if distractors were likewise displayed in a range of 2– $20 \times$ distractor CDT. This was taken into account in subsequent experiments.

3.2.3. Correlation analysis

Contrary to our expectations, targets of high contrast that produced short latency saccades were perturbed more strongly than saccades to low-contrast targets that produced long latencies. To

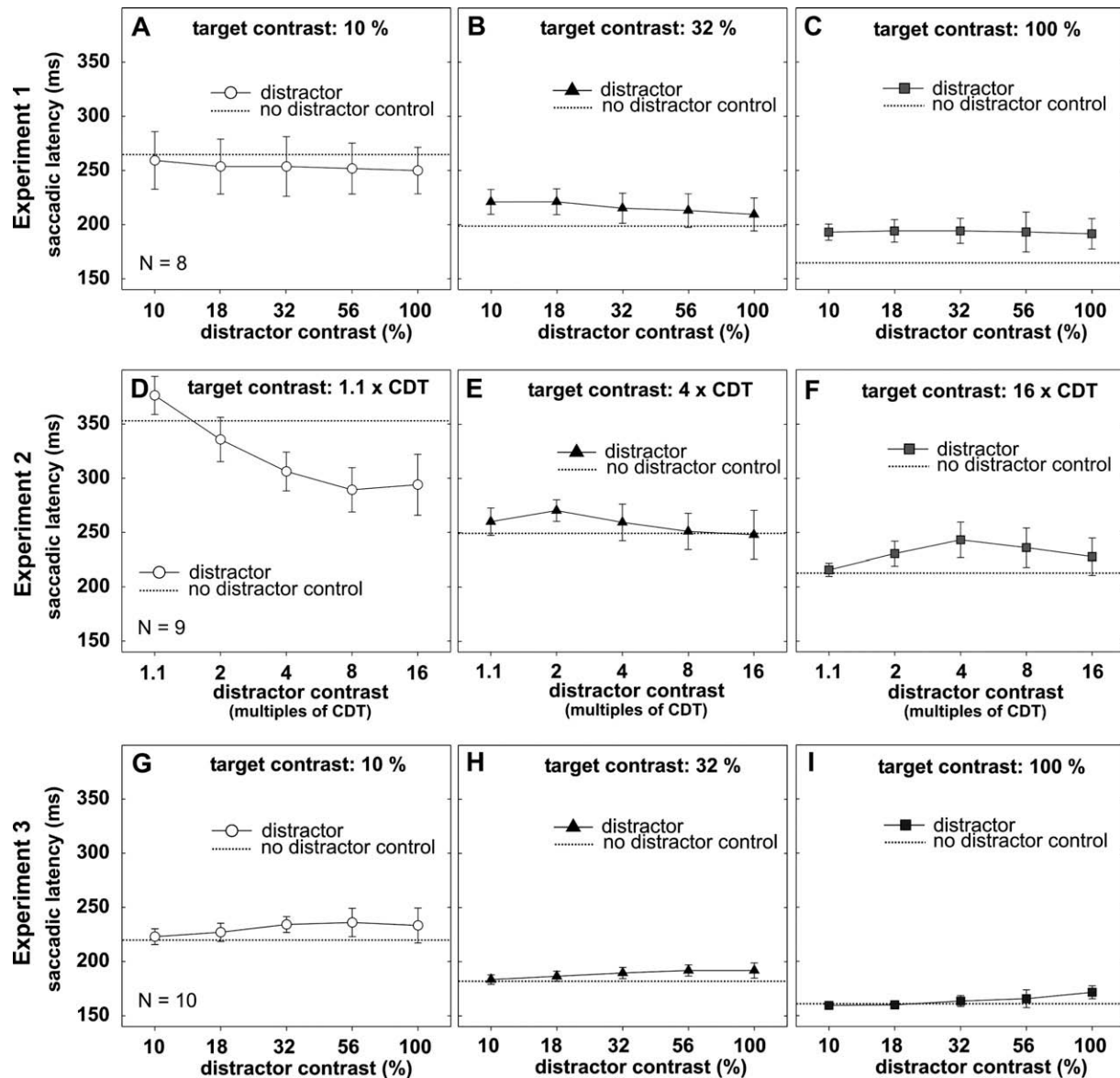


Fig. 3. Saccadic latencies as a function of distractor and target contrast in Experiments 1–3. Contrast was varied in terms of absolute contrast in Experiment 1 (A–C) and Experiment 3 (G–I), and in terms of multiples of contrast detection threshold (CDT) in Experiment 2 (D–F). The thick dotted lines show mean latency for the no distractor control condition. Error bars represent the 95% confidence interval of the difference between distractor and no distractor trials (i.e. of the remote distractor effect, RDE). Thus, if error bars do not cross the line of the control condition, the RDE is significantly different from zero ($p < .05$). If error bars are not visible, they are covered entirely by the corresponding symbol.

further examine this effect we calculated the mean RDE of every subject in the three target contrast conditions and correlated these values with mean saccadic latencies (mean of distractor and no distractor control trials). We obtained a highly significant Pearson correlation of $r = -.65, p = .001, n = 24$ (8 subjects \times 3 target contrast conditions). This finding suggests that it might not be the manipulation of target contrast as such that is responsible for the effects in the ANOVA. Rather, target contrast determines saccadic latency, which in turn might have influenced the RDE. Fig. 4A shows the corresponding scatter plot and the resulting regression line. Note that facilitation effects of up to 60 ms were observed. Various authors suggested that a distractor can act as a warning signal for the onset of the upcoming target (Ross & Ross, 1980, 1981; Walker et al., 1995). In these studies the SOA between target and distractor onset was varied. Facilitation effects emerged when the distractor was presented at least 100 ms before the target, indicating that the warning effect evolves rather slowly. We propose that such a warning effect may also occur with simultaneous distractors if the saccade

target is not very salient and saccadic latencies are therefore relatively long (as in our low target contrast condition).

4. Experiment 2

In Experiment 2, we intended to match the ranges of subjective distractor and target contrast by using multiples of CDT as contrast units.

4.1. Methods

Eight first-year psychology students and one graduate student of the University of Geneva participated in Experiment 2. None of the observers had taken part in Experiment 1. First-year students received normal or corrected to normal vision and ranged from 18 to 48 years of age. CDTs in Experiment 2 were determined by means of staircase procedures. Subjects judged in which of two time intervals a target Gabor was presented. The procedures followed a 2-down 1-up rule,

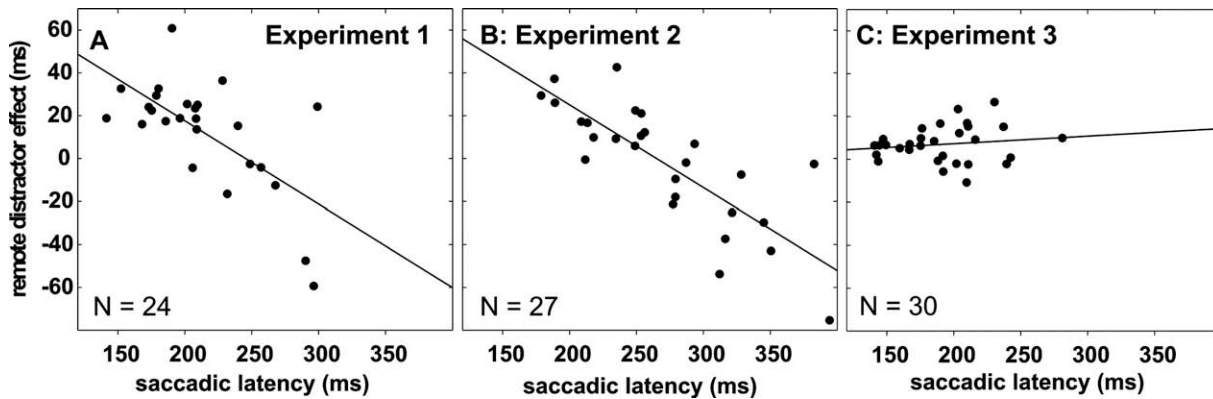


Fig. 4. Remote distractor effect (RDE) as a function of mean saccadic latency in Experiments 1–3. Each data point represents the mean saccadic latency vs. the remote distractor effect for a single subject in one of the three target contrast conditions (e.g. Experiment 1: eight subjects tested in three different target contrast conditions result in 24 data points). Positive values on the ordinate indicate a true RDE, negative values indicate facilitation in the distractor condition compared to the no distractor control trials.

yielding the 71% correct detection threshold (Macmillan & Creelman, 1991). Step size was fixed to 0.2% contrast and the staircase was stopped on the 16th reversal. Participants completed two staircases per stimulus location (central distractor, left target, right target). Stimulus location was blocked and order was counterbalanced across subjects. In the remote distractor paradigm, distractors were displayed centrally at five different multiples of distractor CDT: 1.1 \times , 2 \times , 4 \times , 8 \times and 16 \times CDT. In control trials, the peripheral targets were presented at the same five multiples of target CDT. In distractor trials, targets were only presented at 1.1 \times , 4 \times and 16 \times target CDT. The experiment was run in three 1-h sessions on separate days. In the first session, CDTs were determined. In each of the two subsequent sessions, subjects completed five blocks consisting of 160 trials in the remote distractor paradigm, resulting in 40 trials for each experimental condition. The experiment followed a repeated-measures design. All conditions were presented in a random order and equally distributed across blocks.

4.2. Results and discussion

The staircase procedures of the nine participants converged to mean CDTs of 6.8%, 5.4% and 1.5% for left, right and central Gabors, respectively. Subsequent pairwise *t*-tests revealed that CDTs were substantially higher for peripheral than for central stimuli (left vs. central: $t(8) = 4.46$, $p = .002$; right vs. central: $t(8) = 6.65$, $p < .001$). Although some subjects showed considerable differences between CDTs of left and right stimuli, there was no significant general tendency across all subjects, $t(8) = 1.43$, $p = .190$.

In the remote distractor paradigm, 11.5% of all trials had to be excluded from analysis. Direction errors (5.3%), saccadic landing position errors (3.0%) and no saccade executed (2.0%) were the most frequent errors. Especially low-contrast targets close to CDT produced many direction errors: 14.3% of otherwise valid saccades went into the wrong direction. As subjects knew that there was a target in every trial, they may have occasionally executed a saccade before being sure about where the target was. In this respect, these direction errors are similar to anticipatory saccades, albeit with far longer latencies. Indeed, saccadic latencies were faster for misdirected saccades (290 ms) compared to valid saccades (324 ms) in the low target contrast condition. Moreover, the percentage of misdirected saccades in the low target contrast condition was 11.6% for the no distractor trials and increased slightly to 14.8% in trials with distractor present. Fig. 5B illustrates the saccadic landing positions in Experiment 2. The distribution is very similar to the one obtained in Experiment 1.

4.2.1. Saccadic latencies

Fig. 2 shows mean latencies for the control condition. Again, saccadic latencies decreased with increasing target contrast. This

observation was confirmed by a significant main effect of target contrast, $F(4,32) = 111.89$, $p < .001$, in a subsequent 2 (target direction) \times 5 (target contrast) repeated-measures ANOVA. No further effects reached significance.

4.2.2. Remote distractor effect

Fig. 3D–F illustrates saccadic latencies in the distractor trials as a function of distractor and target contrast. The 2 (target direction) \times 3 (target contrast) \times 5 (distractor contrast) repeated-measures ANOVA revealed main effects of target contrast, $F(2,16) = 37.78$, $p < .001$, as well as distractor contrast, $F(4,32) = 11.67$, $p < .001$. As in Experiment 1, the main effect of target contrast indicates that the RDE increased with increasing target contrast. The main effect of distractor contrast indicates that the RDE decreased with increasing distractor contrast. However, Fig. 3 (compare panels D–F) shows that the effect of distractor contrast varied strongly as a function of target contrast in Experiment 2. Consequently, the ANOVA revealed a highly significant two-way interaction between target and distractor contrast, $F(8,64) = 26.24$, $p < .001$. To follow up on this interaction, we conducted three separate 2 (target direction) \times 5 (distractor contrast) repeated-measures ANOVAs for each target contrast condition. The main effect of distractor contrast remained significant in all three analyses. In the *low target contrast condition* (1.1 \times CDT; Fig. 3D), the RDE decreased with increasing distractor contrast, or rather response facilitation increased with increasing distractor contrast, $F(4,32) = 39.73$, $p < .001$. For *targets presented at 4 \times CDT* (Fig. 3E), a small, but significant decrease of the RDE with increasing distractor contrast was confirmed, $F(4,32) = 3.73$, $p = .013$. In the *high target contrast condition* (16 \times CDT; Fig. 3F), the RDE increased from close to zero to a maximum level of ~ 30 ms with 4 \times CDT distractor contrast, then decreased again for higher distractor contrasts, $F(4,32) = 4.31$, $p = .007$. In sum, a stronger influence of distractor contrast on the RDE was observed when multiples of CDT were used to correct for differences in contrast sensitivity between peripheral and central stimuli. However, the expected increase of the RDE with increasing distractor contrast could only be found for a limited range of distractor and target contrasts. Finally, the interaction between target direction and distractor contrast reached significance in all analyses [$F(4,32) = 4.86$, $p = .004$ in the main analysis; 1.1 \times CDT target condition: $F(4,32) = 2.78$, $p = .044$; 4 \times CDT target contrast condition: $F(4,32) = 3.74$, $p = .013$; 16 \times CDT target contrast condition: $F(4,32) = 2.80$, $p = .042$]. These interactions resulted from stronger RDE modulations by distractor contrast when the saccades were executed to the right (except for the 16 \times CDT target contrast condition in which the RDE modulation is stronger for leftward saccades). In no case did the influence of distractor contrast on the

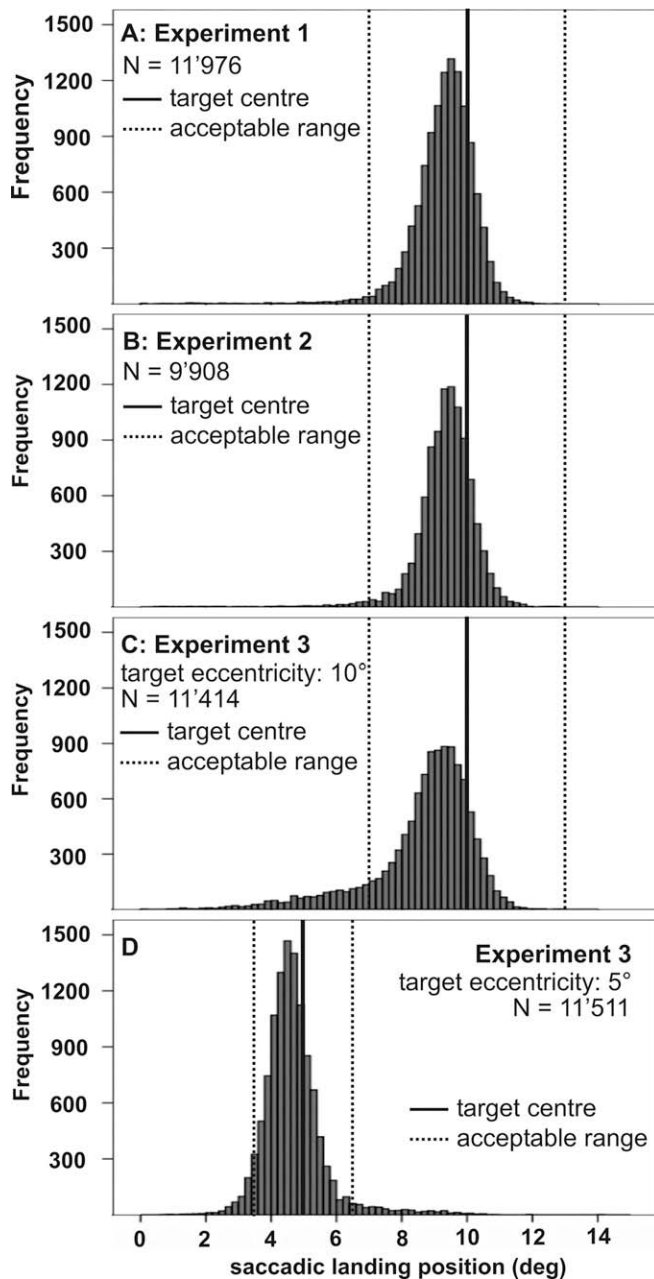


Fig. 5. Distribution of saccadic landing positions in Experiments 1–3. Solid lines mark the position of the target centre. Dotted lines mark the range of saccadic landing positions that were considered acceptable. All saccades that are shown in the histograms were otherwise valid (appropriate latency, etc.).

RDE change its overall pattern across target directions. A table presenting the RDE values for left and right saccades in Experiment 2 is enclosed in [Appendix B](#).

4.2.3. Correlation analysis

As in Experiment 1, we correlated mean saccadic latencies with mean RDE values of the nine subjects in the three target contrast conditions. Again, the Pearson correlation revealed a highly significant negative correlation of $r = -.80$, $p < .001$, $n = 27$. [Fig. 4B](#) shows the corresponding scatter plot and linear regression line.

5. Experiment 3

Experiment 3 was conducted to examine whether results would change when distractors were presented peripherally.

5.1. Methods

Eleven first-year psychology students and one graduate student of the University of Geneva participated in Experiment 3. None of the observers took part in Experiment 1 or Experiment 2. First-year students received course credit for their participation. All observers reported normal or corrected to normal vision and ranged from 18 to 50 years of age. As all stimuli were presented peripherally, CDTs for targets and distractors should be approximately equal. Thus, we varied contrast in terms of absolute contrast. The same contrast conditions as in Experiment 1 were employed. To unequivocally designate which of the two stimuli was the target, target direction was blocked. Participants completed eight blocks with left targets, and eight blocks with right targets. Initial target direction was counterbalanced across subjects. In addition to using a random delay of 500–1200 ms until target appearance, we presented the target at two possible eccentricities (5° and 10°) to prevent subjects from anticipating the target. To be able to examine possible interactions, distractors were presented at these two eccentricities as well. Like the contrast variables, target and distractor eccentricity were varied orthogonally. The experiment was run in three 1-h sessions of 5, 5 and 6 blocks, respectively. In total, this amounted to 16 trials per experimental condition. With the exception of target direction, all conditions were randomly interleaved.

5.2. Results and discussion

Data of two subjects were excluded from analysis due to high percentages of invalid trials (40.7% and 55.0%, respectively). For the remaining 10 subjects, a total of 18.8% of the trials was discarded. Saccadic landing position errors (12.5%) were by far the most frequent errors, followed by anticipations (3.7%) and blinks (2.1%). Interestingly, 20% of the saccades with erroneous landing position were anticipations, indicating a speed-accuracy trade-off. [Fig. 5C](#) and [D](#) illustrates the saccadic landing positions in Experiment 3. As for Experiment 1 and 2, the distributions include valid trials and trials that were excluded because of a horizontal landing position error. [Fig. 5C](#) demonstrates that the distribution for targets at 10° eccentricity shows a left tail that is clearly more prominent than in the first two experiments, resulting in more trials outside the lower limit for valid saccades. For targets at 5° of eccentricity ([Fig. 5D](#)), errors of landing position were not only saccadic undershoots. Rather, they were equally likely due to undershoots as overshoots. Note, that there was an extended right tail in the distribution that was not evident in the other distributions. We conclude that saccades in Experiment 3 were biased towards the centre of the two possible target locations.

5.2.1. Saccadic latencies

[Fig. 2](#) summarizes saccadic latencies as a function of target contrast and eccentricity in the no distractor control conditions of Experiment 3. First of all, it is noteworthy that overall saccadic reaction times were faster than in the previous experiments. Nevertheless, latencies decreased with increasing target contrast for both target eccentricities. We ran a 2 (target direction) \times 5 (target contrast) \times 2 (target eccentricity) repeated-measures ANOVA to analyse the data. As expected, it revealed a significant main effect of target contrast, $F(4,36) = 52.88$, $p < .001$. The main effect of target eccentricity reached significance as well, $F(1,9) = 14.64$, $p = .004$, indicating that saccadic latencies were ~ 13 ms faster for the near target. No other effect reached significance.

5.2.2. Remote distractor effect

[Fig. 3G–I](#) summarizes saccadic latencies in distractor and the corresponding no distractor control trials as a function of distractor

and target contrast. It is obvious that the perturbation by peripheral distractors was relatively weak overall. To analyse the data, we performed an ANOVA including all possible target and distractor variables, resulting in a 2 (target direction) \times 3 (target contrast) \times 2 (target eccentricity) \times 5 (distractor contrast) \times 2 (distractor eccentricity) repeated-measures analysis. In contrast to the previous experiments, there was only a marginally significant main effect of target contrast, $F(2,18) = 3.39$, $p = .056$, pointing to a slightly decreasing RDE with increasing target contrast. The analysis also revealed a significant main effect of distractor contrast, $F(4,36) = 5.50$, $p = .001$, indicating an increase in RDE with increasing distractor contrast. Although these results are in line with our initial hypotheses, the RDE modulation is clearly weaker than in the previous experiments.

Concerning stimulus eccentricity, the ANOVA revealed a significant main effect of distractor eccentricity, $F(1,9) = 5.84$, $p = .039$, indicating that the RDE was larger with a distractor at 5° than with a distractor at 10° (9 ms vs. 5 ms, respectively). This confirms the results of previous studies (Griffiths et al., 2006; Honda, 2005; Walker et al., 1997). Furthermore, the three-way interactions between target direction, distractor contrast and target contrast, $F(8,72) = 2.33$, $p = .028$, and between target contrast, target eccentricity and distractor eccentricity, $F(2,18) = 4.54$, $p = .025$, reached significance. There was a significant four-way interaction between target contrast, target eccentricity, distractor contrast, and distractor eccentricity, $F(8,72) = 2.31$, $p = .029$, and a significant five-way interaction between all variables entered into analysis, $F(8,72) = 2.78$, $p = .010$. A Figure comparing saccadic latencies in all possible factor combinations is enclosed in Appendix C. Inspection of the data pattern did not yield any obvious interpretations for these effects. The main effects of target and distractor contrast and distractor eccentricity are stronger in some conditions, weaker in others and sometimes appear to vanish. Importantly, they do not reverse in any condition (except in the first panel in the second row of Appendix C: here the RDE seems to decrease with increasing distractor contrast larger than 18% for distractors at 5° of eccentricity). Therefore we conclude that the higher-level interactions do not compromise the major conclusions of our study and we will not interpret them any further.

5.2.3. Correlation analysis

Correlating saccadic latency with the RDE resulted in a positive but very weak Pearson coefficient of $r = .15$, $p = .442$, $n = 30$. Fig. 4C demonstrates that the variability in the saccadic latency as well as the RDE distributions were greatly diminished compared to Experiments 1 and 2.

6. General discussion

The current study examined whether target and distractor properties influence the RDE. Specifically, we expected that target properties that yield fast saccadic latencies when no distractor is present would reduce the impact of a simultaneously presented distractor. If, however, this property was present in the distractor, it should increase the size of the RDE. When varying target and distractor contrast simultaneously, we did not consistently observe the predicted pattern of results. High-contrast targets were more efficient than low-contrast targets as they decreased saccadic latency. However, the only support for the hypothesis that efficient targets make saccades immune to distractors and that efficient distractors produce larger RDEs comes from Experiment 3 in which distractors were presented peripherally. In Experiment 3 the RDE was indeed very small with high-contrast targets and increased with increasing distractor contrast. Experiments with central distractors (Experiments 1 and 2) showed the opposite pattern: The RDE was larger with high-contrast targets and high-contrast dis-

tractors did not consistently produce stronger RDEs. Instead, in Experiment 1 and in most conditions of Experiment 2 the RDE did not change or even decreased with increasing distractor contrast. How can these results be explained?

6.1. Temporal overlap between target- and distractor-related activity

Studies manipulating the SOA between target and distractor have found that a distractor stimulus perturbs saccadic latencies only when it is presented within ~ 100 ms or less of target onset (Ross & Ross, 1980, 1981; Walker et al., 1995; White et al., 2005). To account for these results, it was suggested that visual onsets lead only to a transient discharge of the corresponding neuronal populations in the saccade map. The neuronal signal of the distractor-related activity might either decay passively (Kopeck, 1995; Trappenberg et al., 2001), or selective top-down suppression at the distractor location might be responsible for its short-lived impact (Godijn & Theeuwes, 2002; Wijnen & Ridderinkhof, 2007). In any case, the transient discharges at the distractor location are presumably evoked by scarcely processed sensory information that can reach the map very fast (Trappenberg et al., 2001).

The fast but transient nature of the inhibition implies that a distractor can only disrupt saccade initiation when distractor-related activity coincides with target-related activity. Put differently, if distractor-related activity has already subsided when target-related activity reaches the saccade map, no perturbing effect will occur. Similarly, if target-related activity has already reached the threshold of saccade initiation before distractor-related activity arrives in the map, no effect will be observed, either.

To explain our results, we propose that stimulus contrast influences the point in time when stimulus-related activity starts to rise in the saccade map: the higher the stimulus contrast, the earlier the response in the map. Furthermore, stimulus eccentricity might mediate these effects: the CDTs observed in Experiment 2 clearly demonstrate that contrast sensitivity is reduced for peripheral compared to foveal stimuli. Thus, a foveal stimulus might reach the oculomotor system faster than a peripheral stimulus of the same absolute contrast.

Given these assumptions, we propose that for the low (10%) contrast targets in Experiment 1, neuronal signals from the foveally presented distractors arrived much earlier in the saccade map than signals from the peripheral targets. Taking into account the transient nature of distractor-related activity, it might already have subsided when target-related signals reached the saccade map. Thus, the distractor could not disrupt the initiation of the saccade (see Fig. 3A). A similar explanation has been proposed in a study by Ludwig and Gilchrist (2002) in which oculomotor capture by an abrupt onset was found to be stronger than capture of manual pointing movements. The authors argue that fast saccadic responses are affected more than slow manual responses due to the decline of the distractor's potential to compete with the target. Note that the temporal lag of the target-related response should be reduced for higher target contrasts. Consistent with this assumption, we found the RDE to increase with increasing target contrast. Conversely, high distractor contrast should increase the temporal advantage of the distractor-related response, resulting in a larger temporal separation between target- and distractor-related activity. Accordingly, the RDE decreased slightly with increasing distractor contrast.

In Experiment 2, we tried to control for the differential contrast sensitivity for foveal and peripheral stimuli by using multiples of CDT as contrast units. In such a setting, target- and distractor-related information should reach the saccade map simultaneously if they are displayed at the same contrast (in terms of multiples of CDT). Hence, we would expect an interaction between target and distractor contrast: saccades to low contrast targets should

be most strongly disrupted by low-contrast distractors, saccades to high-contrast targets should be most strongly disrupted by high-contrast distractors. In fact, Fig. 3D–F hints at such a cross-over interaction. For the lowest $1.1\times$ CDT target contrast, the graph shows a RDE peak at the corresponding $1.1\times$ CDT distractor contrast. For the $4\times$ CDT and $16\times$ CDT target contrasts, the RDE peaks at distractor contrasts which are slightly lower than the corresponding target contrast. To account for the small mismatches, we presume that the multiples of CDT approach might have been too noisy to perfectly match the contrast values of the foveal and peripheral stimuli. Alternatively, facilitation might have reduced the perturbing influence of the distractor at higher distractor contrasts, thus shifting the RDE peak to slightly lower distractor contrasts (see discussion of the facilitation effects below).

In sum, we propose that the temporal overlap between target- and distractor-related signals in the saccade map determines the magnitude of the RDE. This temporal overlap is mediated by target and distractor contrast as contrast determines how fast stimulus-related information reaches the saccade map. Although this explanation can account for the findings of Experiment 1 and Experiment 2, there remain at least two questions unanswered. First, it is still unclear why the RDE was reversed in the low target contrast conditions of Experiment 1 and particularly Experiment 2. Second, it is not evident why the results of Experiment 3 do not show a similar interaction as in Experiment 2.

6.2. Distractors as warning signals

There is some evidence that a distractor may serve two functions in the remote distractor paradigm. First, it acts as a true distractor perturbing saccade initiation. Second, it might act as a warning signal that facilitates saccade initiation. So far, facilitation effects have only been reported when the distractor was presented at least 100 ms before the target, indicating that the warning effect builds up rather slowly (Ross & Ross, 1980, 1981; Walker et al., 1995; however, White et al. (2005) found facilitation effects for a background change at a distractor-target SOA of 50 ms). It is not impossible, though, that these warning effects might also occur when target and distractor are presented simultaneously, provided saccadic reaction times to the target are sufficiently long to allow for the warning effect to evolve. This explanation is supported by the observation that facilitation (reversed RDE) increases with increasing saccadic latency (see correlation analyses in Fig. 4A and B). This might also explain why the RDE diminishes slightly with increasing distractor contrast in some conditions of our experiments: due to faster processing times, the warning reaches the system sooner with high-contrast than with low-contrast distractors.

In sum, we postulate two opposing functions of the distractor in our setting: a fast but transient perturbing effect and a slowly evolving facilitation effect. The two effects overlay and partly absorb each other and may both be mediated by distractor contrast.

6.3. Preparatory mechanisms speed up saccadic latencies

Still, it is unclear why the results of Experiment 3 did not show an interaction of target and distractor contrast as in Experiment 2. Instead, the RDE slightly increased with increasing distractor contrast and showed a weak trend to decrease with increasing target contrast. As targets and distractors were both presented peripherally an explanation based on differential contrast sensitivity can be ruled out.

The most straightforward explanation is that Experiment 3 was the only experiment in which target direction was known in advance. There is convincing evidence that predictability of target direction speeds up saccadic latency (Carpenter, 2004; Carpenter

& Williams, 1995). Accordingly, saccadic latencies were reduced in Experiment 3. These modulations may be linked to preparatory activation at the target location prior to target onset. Similar motor preparation processes are proposed to account for the reduced saccadic latencies under low target location uncertainty when a gap period is introduced between fixation point offset and target onset (see Rolfs & Vitu, 2007). In our experiments, there were always two possible target locations (at 5° or 10° on one side in Experiment 3, at 10° on either side in the previous experiments). However, the distance between those two possible target locations was smaller in Experiment 3 than in the first two experiments (5° compared to 20°). Following the idea that the saccade map is organized in a manner that nearby locations are influenced via excitatory connections whereas distant locations are inhibited (e.g. Findlay & Walker, 1999; Godijn & Theeuwes, 2002; Kopeck, 1995; Trappenberg et al., 2001), it might be possible that the two target locations in Experiment 3 were still in each other's excitatory range. This would lead to stronger motor preparation in Experiment 3 than in the previous experiments. Alternatively, attentional mechanisms might account for the reduced saccadic latencies in Experiment 3. The size of the attentional focus is known to be variable (Eriksen & St James, 1986). Moreover, it has been demonstrated that the efficiency of processing decreases with increasing size of the attentional focus (Castiello & Umiltà, 1990). As the two possible target locations were substantially closer to each other in Experiment 3, the attentional focus encompassing both target locations was far smaller than in the first two experiments. Thus, target processing might have been speeded up, resulting in shorter response onset latencies in the saccade map. Our finding that saccadic accuracy was reduced in Experiment 3 and that erroneous saccades were biased towards the alternative target location supports both explanations, advanced motor preparation and the attentional zoom lens.

Whatever the exact mechanism, we propose that there was a temporal advantage of target-related activity compared to distractor-related activity in Experiment 3. Hence, target-related activity arrived before distractor-related activity and only the fastest distractor signals (i.e. high-contrast distractors) were able to disturb its rise to threshold. The result is an increasing RDE with increasing distractor contrast. Furthermore, the "head-start" of target-related activity increases with increasing target contrast, explaining the marginally decreasing RDE and the barely significant RDE at the highest target contrast. Still, the question remains why the effect of target contrast was only marginally significant in Experiment 3 while the previous experiments produced such strong (but inverted) effects. Note, that the changes in saccadic latencies across target contrast levels were smaller in Experiment 3 than in the previous experiments (Fig. 3). This is also evident in Fig. 4C, demonstrating that the variability of saccadic latencies was reduced in Experiment 3 compared to Experiment 1 and 2 (Fig. 4A and B). The reduced variability may have precluded modulations of the RDE by target contrast. This might also explain why Ludwig et al. (2005, Experiment 3) did not find an effect of target contrast. They also used peripheral Gabors as targets and distractors, varying the contrast of the target in three steps: 20%, 50% and 80%. Saccadic latencies varied even less across the three target contrast conditions than in our Experiment 3 (cf. Ludwig et al., 2005, Fig. 3).

To summarize, not only target properties (e.g. target contrast), but also the experimental settings (e.g. predictability of target location) modulate saccadic latencies. We propose that the magnitude of the RDE is strongly linked to the overall saccadic latencies in a given condition. They indicate at which point in time target-related activity arrives in the saccade map, which in turn, determines whether the transient effect of the distractor coincides with a stage of target processing that is vulnerable to perturbation. A similar argument has been made by Reingold and Stampe (2002) who varied saccadic

latencies by employing different experimental paradigms (gap, step, overlap and antisaccade paradigm). They argued that saccade inhibition should be similar in all paradigms if the distractor was presented 100 ms before the mean saccadic latency of the respective condition. Thus, they varied target to distractor SOA according to the mean latencies in control trials. The results show that despite differences in SOA of up to 130 ms, the overall delay in saccadic reaction time in distractor trials compared to the no distractor control trials was quite stable in magnitude across paradigms (about 20 ms, see Reingold & Stampe, 2002, Table 1).

6.4. Comparing RDE models: Competitive inhibition in a uniform saccade map or activation of the fixate centre?

So far, we discussed our results more in terms of a uniform saccade map account of the RDE, in which target and distractor produce two distinct activity peaks that mutually inhibit each other via inhibitory connections between all distant locations in the map (Godijn & Theeuwes, 2002; Kopecz, 1995; Trappenberg et al., 2001). Note however, that our propositions are also compatible with the model proposed by Findlay and Walker (1999). For instance, the influence of the distractor on the *fixate centre* might also be transient and thus already reduced when target-related activity reaches the *move centre* in the low target contrast conditions of Experiment 1. Furthermore, although the model does not include motor preparation processes, they might be easily incorporated. Motor preparation mechanisms as those postulated in Experiment 3 might shift the balance between the *move* and the *fixate centre* towards the *move centre*, allowing for activity in the *fixate centre* to fall below threshold before distractor-related activity can take effect. Hence, our results and the proposed explanation do not favour one account of the RDE over the other.

6.5. Neurophysiology

In our discussion of the results we deliberately concentrated on functional explanations. However, there are some neurophysiological findings that support our interpretations. Most studies focus on processes in the intermediate layers of the superior colliculus (SC). The SC is a midbrain structure known to play an important role in saccade generation. Its neurons are arranged in a retinotopically organized motor map, coding for different saccade directions and amplitudes and some cells also respond to abrupt visual onsets with a burst of activity at the corresponding location (see Munoz, Dorris, Pare, & Everling, 2000; Sparks, 2002 for recent reviews). The cells of the collicular map interact via lateral interconnections, activating nearby locations but inhibiting distant locations. This results in push–pull relations between subpopulations of cells in all regions of the ipsilateral and contralateral SC (Dorris, Olivier, & Munoz, 2007; Munoz & Istvan, 1998; Olivier, Dorris, & Munoz, 1999; Trappenberg et al., 2001), similar to the processes proposed in the uniform saccade map account of the RDE (Godijn & Theeuwes, 2002; Kopecz, 1995; Trappenberg et al., 2001). Furthermore, there is evidence that the inhibitory effect of the distractor is only transient in nature. The burst of activity in the SC following abrupt onsets lasts only about 50 ms before it quickly subsides again (Dorris et al., 2007). Following the inhibitory connections between distant locations of the collicular map, a corresponding transient drop of activity at distant locations has also been reported that recovers just as fast (Dorris et al., 2007). Most important for our assumptions, a recent study found reduced response onset latencies of activity in the intermediate layers of the SC for high luminance stimuli compared to stimuli of low luminance (Bell, Meredith, Van Opstal, & Munoz, 2006). The authors argue that stimuli of high intensity are processed faster at the retinal level. Therefore, related infor-

mation reaches the SC earlier which results in shorter saccade latencies. Concerning advanced motor preparation, some authors found that pre-target activity in a subpopulation of SC neurons (so-called build-up cells, Munoz & Wurtz, 1995) increases with increasing predictability of the target location, resulting in shorter saccadic latencies (Basso & Wurtz, 1998; Dorris & Munoz, 1998). The movement fields of build-up cells have been found to be open-ended, that is, they often exhibit a response not only to saccades of a specific direction and amplitude but also to saccades of the same direction but of an amplitude significantly larger than their optimal amplitude (Dorris, Pare, & Munoz, 1997; Munoz & Wurtz, 1995). This could be an additional explanation why advance motor preparation might be stronger for two targets of equal direction but different amplitudes (Experiment 3) than for two targets of equal amplitude but different direction (Experiments 1 and 2).

7. Conclusions

Consistent with previous accounts, we propose that the RDE is a low-level effect that can be explained by competitive interaction between subpopulations of neurons responding to target and distractor. Stimulus properties, task demands or experimental instructions might change its magnitude by modifying the arrival times of distractor and target-related signals in the structure where the presumed competitive interaction takes place. The temporal overlap between target- and distractor-related responses determines whether the transient effect of the distractor coincides with a stage of target processing that is vulnerable to perturbation.

Acknowledgments

We thank Françoise Vitu and Casimir Ludwig for helpful comments on previous versions of this manuscript. Both authors were supported by the Swiss National Foundation PDFM1-114417.

Appendix A

Mean remote distractor effect (RDE in ms) and corresponding standard error (SE) as a function of target direction, target contrast and distractor contrast in Experiment 1.

| Target contrast (%) | Distractor contrast (%) | Target direction | | | |
|---------------------|-------------------------|------------------|-------|-------|-------|
| | | Left | | Right | |
| | | RDE | SE | RDE | SE |
| 10 | 10 | -2 | 9.61 | -9 | 12.90 |
| | 18 | -9 | 8.36 | -13 | 13.75 |
| | 32 | -8 | 10.26 | -15 | 13.30 |
| | 56 | -8 | 7.53 | -18 | 12.88 |
| | 100 | -5 | 7.48 | -25 | 13.57 |
| 32 | 10 | 25 | 3.96 | 20 | 6.04 |
| | 18 | 27 | 5.67 | 18 | 5.94 |
| | 32 | 21 | 5.00 | 12 | 7.13 |
| | 56 | 18 | 6.17 | 10 | 7.58 |
| | 100 | 13 | 5.03 | 8 | 8.06 |
| 100 | 10 | 35 | 7.86 | 22 | 3.73 |
| | 18 | 32 | 5.69 | 27 | 3.82 |
| | 32 | 35 | 7.59 | 25 | 3.79 |
| | 56 | 32 | 8.36 | 26 | 7.47 |
| | 100 | 33 | 8.12 | 21 | 4.41 |

Note: Positive values indicate a true RDE, negative values indicate facilitation in the distractor condition compared to the no distractor control trials.

Appendix B

Mean remote distractor effect (RDE in ms) and corresponding standard error (SE) as a function of target direction, target contrast and distractor contrast in Experiment 2.

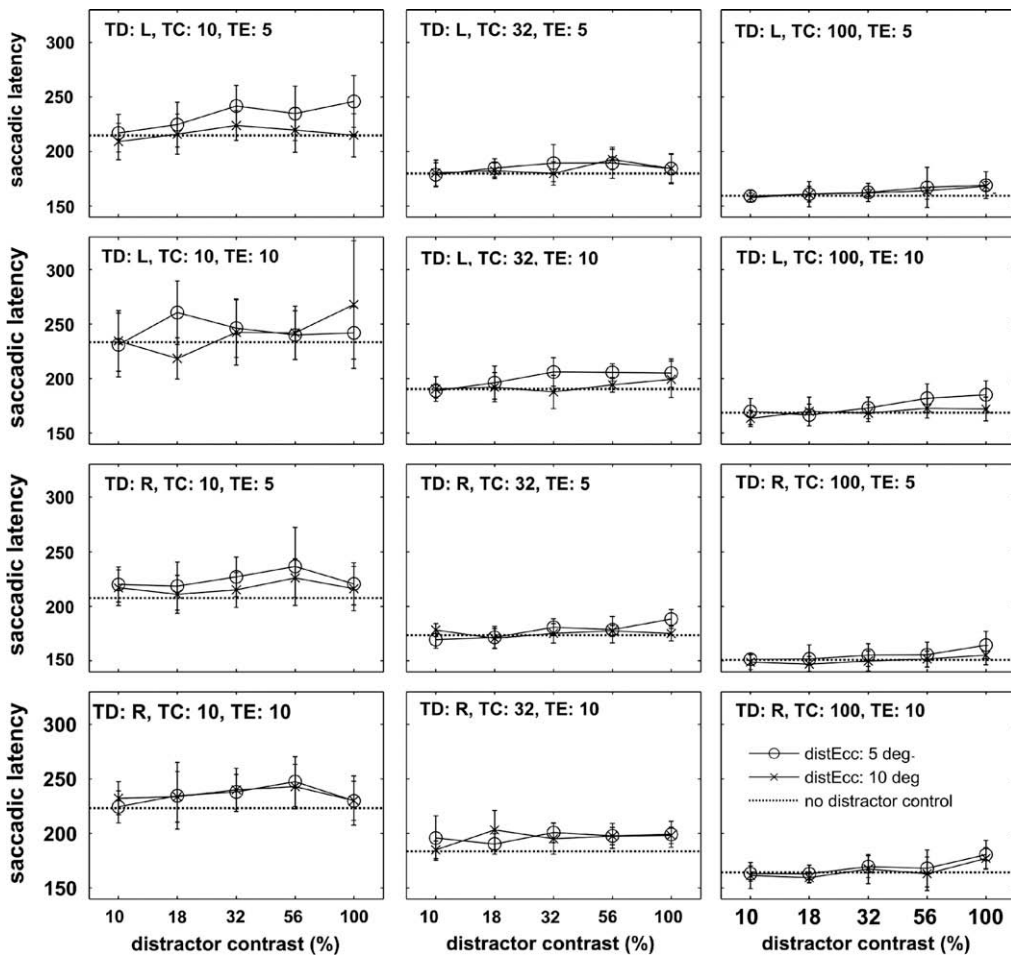
| Target contrast | Distractor contrast | Target direction | | | |
|-----------------|---------------------|------------------|-------|-------|-------|
| | | Left | | Right | |
| | | RDE | SE | RDE | SE |
| 1.1× CDT | 1.1× CDT | 15 | 8.08 | 32 | 17.19 |
| | 2× CDT | -13 | 12.02 | -21 | 10.53 |
| | 4× CDT | -43 | 15.13 | -50 | 7.10 |
| | 8× CDT | -54 | 10.41 | -73 | 11.19 |
| 16× CDT | 1.1× CDT | -53 | 17.18 | -65 | 13.86 |

Appendix B. (continued)

| Target contrast | Distractor contrast | Target direction | | | |
|-----------------|---------------------|------------------|------|-------|-------|
| | | Left | | Right | |
| | | RDE | SE | RDE | SE |
| 4× CDT | 1.1× CDT | 8 | 9.18 | 13 | 3.82 |
| | 2× CDT | 25 | 7.12 | 17 | 7.95 |
| | 4× CDT | 18 | 7.25 | 2 | 9.11 |
| | 8× CDT | 13 | 5.81 | -10 | 10.05 |
| | 16× CDT | 11 | 8.79 | -14 | 13.49 |
| 16× CDT | 1.1× CDT | 0 | 2.83 | 6 | 4.23 |
| | 2× CDT | 10 | 4.92 | 25 | 7.10 |
| | 4× CDT | 31 | 7.67 | 29 | 7.84 |
| | 8× CDT | 23 | 7.90 | 23 | 8.44 |
| | 16× CDT | 12 | 7.43 | 18 | 7.96 |

Note: Positive values indicate a true RDE, negative values indicate facilitation in the distractor condition compared to the no distractor control trials.

Appendix C



Saccadic latency (in ms) as a function of target direction (TD: L, left; R, right), target contrast (TC: Michelsen contrast in %), target eccentricity (TE: in degrees of visual angle), distractor contrast and distractor eccentricity (distEcc) in Experiment 3. The thick dotted lines show mean latency for the no distractor control condition. Error bars represent the 95% confidence interval of the difference between distractor and no distractor trials (i.e. of the remote distractor effect, RDE). Thus, if error bars do not cross the line of the control condition, the RDE is significantly different from zero ($p < .05$).

References

- Adler, S. A., Bala, J., & Krauzlis, R. J. (2002). Primacy of spatial information in guiding target selection for pursuit and saccades. *Journal of Vision*, 2, 627–644.
- Basso, M. A., & Wurtz, R. H. (1998). Modulation of neuronal activity in superior colliculus by changes in target probability. *Journal of Neuroscience*, 18(18), 7519–7534.
- Bell, A. H., Meredith, M. A., Van Opstal, A. J., & Munoz, D. P. (2006). Stimulus intensity modifies saccadic reaction time and visual response latency in the superior colliculus. *Experimental Brain Research*, 174(1), 53–59.
- Benson, V. (2008). A comparison of bilateral versus unilateral target and distractor presentation in the remote distractor paradigm. *Experimental Psychology*, 55(5), 334–341.
- Carpenter, R. H. (2004). Contrast, probability, and saccadic latency: evidence for independence of detection and decision. *Current Biology*, 14(17), 1576–1580.
- Carpenter, R. H., & Williams, M. L. (1995). Neural computation of log likelihood in control of saccadic eye movements. *Nature*, 377(6544), 59–62.
- Castiello, U., & Umiltà, C. (1990). Size of the attentional focus and efficiency of processing. *Acta Psychologica*, 73(3), 195–209.
- Doma, H., & Hallett, P. E. (1988a). Dependence of saccadic eye-movements on stimulus luminance, and an effect of task. *Vision Research*, 28(8), 915–924.
- Doma, H., & Hallett, P. E. (1988b). Rod-cone dependence of saccadic eye-movement latency in a foveating task. *Vision Research*, 28(8), 899–913.
- Dorris, M. C., & Munoz, D. P. (1998). Saccadic probability influences motor preparation signals and time to saccadic initiation. *Journal of Neuroscience*, 18(17), 7015–7026.
- Dorris, M. C., Olivier, E., & Munoz, D. P. (2007). Competitive integration of visual and preparatory signals in the superior colliculus during saccadic programming. *Journal of Neuroscience*, 27(19), 5053–5062.
- Dorris, M. C., Pare, M., & Munoz, D. P. (1997). Neuronal activity in monkey superior colliculus related to the initiation of saccadic eye movements. *Journal of Neuroscience*, 17(21), 8566–8579.
- Eriksen, C. W., & St James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysics*, 40(4), 225–240.
- Findlay, J. M., & Walker, R. (1999). A model of saccade generation based on parallel processing and competitive inhibition. *The Behavioral and Brain Sciences*, 22(4), 661–674. discussion 674–721.
- Fredericksen, R. E., Bex, P. J., & Verstraten, F. A. (1997). How big is a Gabor patch, and why should we care? *Journal of the Optical Society of America A: Optics, Image Science, and Vision*, 14(1), 1–12.
- Godijn, R., & Theeuwes, J. (2002). Programming of endogenous and exogenous saccades: Evidence for a competitive integration model. *Journal of Experimental Psychology: Human Perception and Performance*, 28(5), 1039–1054.
- Griffiths, H., Whittle, J., & Buckley, D. (2006). The effect of binocular and monocular distractors on saccades in participants with normal binocular vision. *Vision Research*, 46(1–2), 72–81.
- Honda, H. (2005). The remote distractor effect of saccade latencies in fixation-offset and overlap conditions. *Vision Research*, 45(21), 2773–2779.
- Kopecz, K. (1995). Saccadic reaction times in gap/overlap paradigms: A model based on integration of intentional and visual information on neural, dynamic fields. *Vision Research*, 35(20), 2911–2925.
- Lévy-Schoen, A. (1969). Détermination et latence de la réponse oculomotrice à deux stimulus simultanés ou successifs selon leur excentricité relative. *L'Année Psychologique*, 69(2), 373–392.
- Ludwig, C. J., & Gilchrist, I. D. (2002). Stimulus-driven and goal-driven control over visual selection. *Journal of Experimental Psychology: Human Perception and Performance*, 28(4), 902–912.
- Ludwig, C. J., Gilchrist, I. D., & McSorley, E. (2004). The influence of spatial frequency and contrast on saccade latencies. *Vision Research*, 44(22), 2597–2604.
- Ludwig, C. J., Gilchrist, I. D., & McSorley, E. (2005). The remote distractor effect in saccade programming: Channel interactions and lateral inhibition. *Vision Research*, 45(9), 1177–1190.
- Macmillan, N. A., & Creelman, C. D. (1991). *Detection theory: A user's guide*. Cambridge, UK: Cambridge University Press.
- McSorley, E., & Findlay, J. M. (2003). Saccade target selection in visual search: Accuracy improves when more distractors are present. *Journal of Vision*, 3(11), 877–892.
- Munoz, D. P., Dorris, M. C., Pare, M., & Everling, S. (2000). On your mark, get set: Brainstem circuitry underlying saccadic initiation. *Canadian Journal of Physiology and Pharmacology*, 78(11), 934–944.
- Munoz, D. P., & Istvan, P. J. (1998). Lateral inhibitory interactions in the intermediate layers of the monkey superior colliculus. *Journal of Neurophysiology*, 79(3), 1193–1209.
- Munoz, D. P., & Wurtz, R. H. (1995). Saccade-related activity in monkey superior colliculus: I. Characteristics of burst and buildup cells. *Journal of Neurophysiology*, 73(6), 2313–2333.
- Olivier, E., Dorris, M. C., & Munoz, D. P. (1999). Lateral interactions in the superior colliculus, not an extended fixation zone, can account for the remote distractor effect. *Behavioral and Brain Sciences*, 22, 661–721.
- Perron, C., & Hallett, P. E. (1995). Saccades to large coloured targets stepping in open fields. *Vision Research*, 35(2), 263–274.
- Ploner, C. J., Ostendorf, F., & Dick, S. (2004). Target size modulates saccadic eye movements in humans. *Behavioral Neuroscience*, 118(1), 237–242.
- Reingold, E. M., & Stampe, D. M. (2002). Saccadic inhibition in voluntary and reflexive saccades. *Journal of Cognitive Neuroscience*, 14(3), 371–388.
- Rolf, M., & Vitu, F. (2007). On the limited role of target onset in the gap task: Support for the motor-preparation hypothesis. *Journal of Vision*, 7(10), 20–71.
- Ross, L. E., & Ross, S. M. (1980). Saccade latency and warning signals: Stimulus onset, offset, and change as warning events. *Perception & Psychophysics*, 27(3), 251–257.
- Ross, S. M., & Ross, L. E. (1981). Saccade latency and warning signals: Effects of auditory and visual stimulus onset and offset. *Perception & Psychophysics*, 29(5), 429–437.
- Sparks, D. L. (2002). The brainstem control of saccadic eye movements. *Nature Reviews: Neuroscience*, 3(12), 952–964.
- Sumner, P., Adamjee, T., & Mollon, J. D. (2002). Signals invisible to the collicular and magnocellular pathways can capture visual attention. *Current Biology*, 12(15), 1312–1316.
- Trappenberg, T. P., Dorris, M. C., Munoz, D. P., & Klein, R. M. (2001). A model of saccade initiation based on the competitive integration of exogenous and endogenous signals in the superior colliculus. *Journal of Cognitive Neuroscience*, 13(2), 256–271.
- Vitu, F., Lancelin, D., Jean, A., & Farioli, F. (2006). Influence of foveal distractors on saccadic eye movements: A dead zone for the global effect. *Vision Research*, 46(28), 4684–4708.
- Walker, R., Deubel, H., Schneider, W. X., & Findlay, J. M. (1997). Effect of remote distractors on saccade programming: Evidence for an extended fixation zone. *Journal of Neurophysiology*, 78(2), 1108–1119.
- Walker, R., Kentridge, R. W., & Findlay, J. M. (1995). Independent contributions of the orienting of attention, fixation offset and bilateral stimulation on human saccadic latencies. *Experimental Brain Research*, 103(2), 294–310.
- Walker, R., Maurer, D., Pambakian, A. L. M., & Kennard, C. (2000). The oculomotor distractor effect in normal and hemianopic vision. *Proceedings of the Royal Society of London: Biological Sciences*, 267, 431–438.
- White, B. J., Gegenfurtner, K. R., & Kerzel, D. (2005). Effects of structured nontarget stimuli on saccadic latency. *Journal of Neurophysiology*, 93(6), 3214–3223.
- White, B. J., Kerzel, D., & Gegenfurtner, K. R. (2006). The spatio-temporal tuning of the mechanisms in the control of saccadic eye movements. *Vision Research*, 46(22), 3886–3897.
- Wijnen, J. G., & Ridderinkhof, K. R. (2007). Response inhibition in motor and oculomotor conflict tasks: Different mechanisms, different dynamics? *Brain and Cognition*, 63(3), 260–270.