

Congruency effects in the remote distractor paradigm: Evidence for top-down modulation

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In three experiments, we examined effects of target-distractor similarity in the remote distractor effect (RDE). Observers made saccades to peripheral targets that were either gray or green. Foveal or peripheral distractors were presented at the same time. The distractors could either share the target's defining property (congruent) or be different from the target (incongruent). Congruent distractors slowed down saccadic reaction times more than incongruent distractors. The increase of the RDE with target-distractor congruency depended on task demands. The more participants had to rely on the target property to locate the target, the larger the congruency effect. We conclude that the RDE can be modulated in a top-down manner. Alternative explanations such as persisting memory traces for the target property or differences in stimulus arrangement were considered but discarded. Our claim is in line with models of saccade generation which assume that the structures underlying the RDE (e.g. the superior colliculus) receive bottom-up as well as top-down information.

Keywords: eye movements, latency, distractor, top-down

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Introduction

The remote distractor effect (RDE)

In the remote distractor effect (RDE), saccadic latency is prolonged by the onset of a distractor stimulus that appears simultaneously with the target for the saccadic eye movement (Lévy-Schoen, 1969; Walker, Kentridge, & Findlay, 1995). Importantly, the effect only occurs for distractors appearing at more than 20 deg of angular distance from the target (therefore *remote* distractor effect) and its magnitude decreases with increasing distractor eccentricity from the fovea (Walker, Deubel, Schneider, & Findlay, 1997). Models of saccade generation often consider the intermediate and deep layers of the superior colliculus (SC) as a neural correlate of the RDE (Findlay & Walker, 1999; Godijn & Theeuwes, 2002; Kopecz, 1995; Munoz & Fecteau, 2002; Trappenberg, Dorris, Munoz, & Klein, 2001). These models also stress that the SC can receive bottom-up as well as top-down information. Indeed, neurophysiological evidence suggests that many cortical and subcortical structures project onto the SC, including sensory, motor and cognitive areas (Moschovakis, Scudder, & Highstein, 1996; Sparks & Hartwich-Young, 1989). Still, the influence of higher-level mechanisms on the RDE is rarely examined. Studies usually focus on low-level mechanisms, varying target and/or distractor eccentricity (e.g. Griffiths, Whittle, &

Buckley, 2006; Walker et al., 1997), contrast (Born & Kerzel, 2008), spatial frequency (e.g. Ludwig, Gilchrist, & McSorley, 2005) or size (e.g. White, Gegenfurtner, & Kerzel, 2005).

Higher-level influences on the RDE

White et al. (2005) found the RDE to decrease with increasing size of a large textured central distractor. They argued that the visual system might not interpret large textured distractors as figures or objects, but as background. Figure-ground segregation signals are supposed to originate in higher cortical areas that project back to V1 via recurrent feedback connections. From V1 they are passed on to the SC or other oculomotor areas (Lamme, 1995; Super & Lamme, 2007). Thus, the findings of White et al. (2005) might be interpreted as tentative evidence for higher-level influences on the RDE.

More evidence comes from research on the gap effect. The gap effect is the shortening of saccadic latencies when the central fixation stimulus disappears around 200 ms before target onset (e.g. Kingstone & Klein, 1993; Reuter-Lorenz, Hughes, & Fendrich, 1991; Saslow, 1967). This effect has been shown to be modulated by top-down influences (Machado & Rafal, 2000). Interestingly, the RDE and the gap effect are supposed to be mediated by the same neuronal structures (e.g. the SC). Moreover, several studies have shown that the onset of a central or peripheral stimulus prior to target onset can also produce

facilitation, though less than for fixation offsets (L. E. Ross & Ross, 1980; S. M. Ross & Ross, 1981; Walker et al., 1995; White et al., 2005; but see Pratt, Bekkering, & Leung, 2000). Facilitation by onsets is attributed to a general warning effect that may be endogenously driven (Trappenberg et al., 2001) or represent a higher-level, automated process (Findlay & Walker, 1999). It is interesting to note that the same central or peripheral stimuli that slow down responses when presented simultaneously with the target (i.e., the RDE) may produce facilitation when presented a few hundred milliseconds before the target (Kopecz, 1995; L. E. Ross & Ross, 1980; S. M. Ross & Ross, 1981; Walker et al., 1995). Assuming that the warning effect is endogenously driven, this temporal transition from the RDE to a facilitation effect may be seen as a top-down modulation of the RDE.

Adler, Bala, and Krauzlis (2002) investigated the effects of cueing on saccadic latencies. In their first experiment, the cues indicated with 100% validity either the spatial location or the color of an upcoming target. Both types of cues reduced saccadic latency. This was true for trials with a single target, but even stronger for trials in which a distractor was presented simultaneously with the target. In other words, the cues reduced not only saccadic latencies, but also the RDE (i.e., the latency difference between distractor and no distractor trials). The authors explain their results by top-down modulations of attentional allocation and target selection processes. How can such mechanisms influence the saccade system?

We propose that the saccade system can be tuned to a relevant target property (e.g. target color). Only distractors that share this property will disturb the saccade. Distractors that do not share the target property might have smaller or no effects at all. Similar mechanisms were postulated for the attentional system by Folk and colleagues. According to their contingent involuntary capture hypothesis (Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994), only stimuli that correspond to participants' current attentional control setting can capture attention. For instance, one group of participants was asked to report the identity of an onset target, whereas a second group of participants reported the identity of a color target (e.g. Folk et al., 1992). Manual reaction times (RTs) were measured. The results showed that in the onset group, only an onset cue, but not a color cue, captured attention, whereas in the color group, only a color cue, but not an onset cue, captured attention. A similar control or tuning mechanism might also influence the saccade system.

Overview of the current study

We examined whether top-down settings can modulate the RDE. We evaluated whether the effect of a central distractor depended on whether it was identical to the

target (congruent) or different (incongruent). Congruency effects were measured in several designs that differed in the degree to which they encouraged participants to adopt a top-down setting for the target property. Results indicate that top-down settings can influence the RDE and that these modulations are indeed dependent on the “strength” of the adopted set.

We chose to use central distractors as they were found to produce the strongest RDEs (Griffiths et al., 2006; Walker et al., 1997). Modulations of the RDE through top-down settings should be most visible if the effect is strong in the first place. Note that a number of previous studies have used central distractors (Benson, 2008; Born & Kerzel, 2008; Griffiths et al., 2006; Walker et al., 1997; White et al., 2005). To our knowledge, all models that refer to the RDE assume that the effects of central and peripheral distractors essentially rely on the same mechanism (Findlay & Walker, 1999; Godijn & Theeuwes, 2002; Kopecz, 1995; Munoz & Fecteau, 2002; Trappenberg et al., 2001)¹. Furthermore, it was suggested that two distinct neuronal populations exist in the SC that are associated with foveal and peripheral regions (Munoz & Wurtz, 1993a, 1993b). However, the two populations may actually belong to the same class of neurons, but code for microsaccades and regular saccades, respectively (Hafed, Goffart, & Krauzlis, 2009; Munoz & Fecteau, 2002).

Experiment 1

Participants were asked to saccade to gray or green peripheral targets. The target's property remained either constant within a block of trials (blocked design) or was randomly interleaved across trials (mixed design). In some trials, we presented an irrelevant distractor at the central location. We wanted to know whether this central distractor produced a larger effect when it was congruent to the target property, compared to when it was incongruent. If there are top-down influences on the RDE, then a congruency effect should only emerge in the blocked design because subjects knew the property of the upcoming target in advance and could therefore prepare their saccadic system accordingly. In contrast, the mixed design precluded top-down settings because the target property varied unpredictably. Therefore, no congruency effects should occur.

Methods

Participants

Fourteen first-year psychology students at the University of Geneva took part in [Experiment 1](#). All participants

reported normal or corrected to normal vision. They ranged from 17 to 24 years of age and received course credit for their participation.

Stimuli

The central fixation stimulus consisted of a horizontal black line of 3×1 pixels ($0.10^\circ \times 0.03^\circ$) on a gray background (CIE 1976 LUV coordinates: $l = 65.5$, $u' = 0.02$, $v' = 0.36$). Targets and distractors were Gaussian blobs with a standard deviation of 0.42° . They were either gray and darker than the background (peak value: $l = 32.8$, $u' = 0.18$, $v' = 0.45$) or green and displayed at the same luminance as the background ($l = 65.5$, $u' = 0.15$, $v' = 0.5$). Note that we did not use any psychophysical color calibration procedure to individually equate the luminance of the green stimuli to the background for each subject and stimulus eccentricity. Neither did we employ luminance noise. Thus, our color stimuli did probably not exclusively stimulate color pathways. However, their most salient property should be their color.

Equipment

Stimuli were generated using a ViSaGe Visual Stimulus Generator (Cambridge Research Systems Ltd., Rochester, UK) and displayed on a calibrated 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 (width) \times 29.2 cm (height). 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 participant's head was stabilized by a chin and a forehead rest. Viewing conditions were binocular.

Design and procedure

At the beginning of each trial observers fixated the central fixation line. After a random delay of 500–1200 ms the fixation line disappeared and a target Gaussian appeared at 5° of eccentricity randomly either to the left or right on the horizontal meridian. The participants' task was to execute a saccade to the target as fast as possible. Targets could either be gray or green. The target property was either constant within a block of trials (blocked design) or was randomly interleaved (mixed design). On 2/3 of the trials an irrelevant distractor was presented at the center of the screen. The distractor could either be gray or green. That is, it could be either congruent or incongruent with the target. No distractor control, congruent and incongruent distractor trials were randomly interleaved in both the blocked and the mixed designs.

Distractors always appeared simultaneously with the saccade target and observers were asked to ignore them. The sequence of events and the different conditions are illustrated in [Figure 1](#). After saccading to the target, participants returned their gaze to the center to await the beginning of the next trial. Trials were initiated automatically after an intertrial-interval of ~ 1 s, no specific action (e.g. button press) of the observer was required. Additionally, an error message was presented at the end of every invalid trial (for criteria see the next paragraph) that informed the participants about the type of error (no saccade, wrong direction, anticipation, break of fixation, landing position error, blink) and stayed on for two seconds. Participants completed four blocks of 144 trials, two blocks in the blocked design (one with gray targets, one with green targets) and two blocks in the mixed design. Half the participants started with the blocked and half with the mixed design. Within the blocked design, half the participants started with the gray, half with the green target block. The experiment was run in one single session of ~ 50 min.

Analyses

A time window of 250 ms before and 600 ms after target onset was specified for analysis in each trial. Saccade onsets were detected using a velocity criterion of $30^\circ/\text{s}$. Only the first saccade in the time window with an amplitude $> 1^\circ$ 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 center at the time of saccade onset (5) saccadic landing position (horizontal gaze coordinate of the first sample with a velocity $< 30^\circ$) deviated more than 1.5° from the center of the target or (6) the eye tracker lost track between the beginning of the time window and the end of the saccade (e.g. as the result of a blink). The complete data set of a participant 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 participant. The RDEs were calculated by subtracting the median value of the no distractor condition from the corresponding distractor condition.

Results

Two participants were excluded from analysis because of high percentages of invalid trials (62.8% and 35.9%, respectively). For the remaining twelve participants, 10.1% of all trials were discarded from analysis. Saccadic landing position errors (4.9%), blinks (3.6%) and no saccade executed (2.0%) were the most frequent errors.

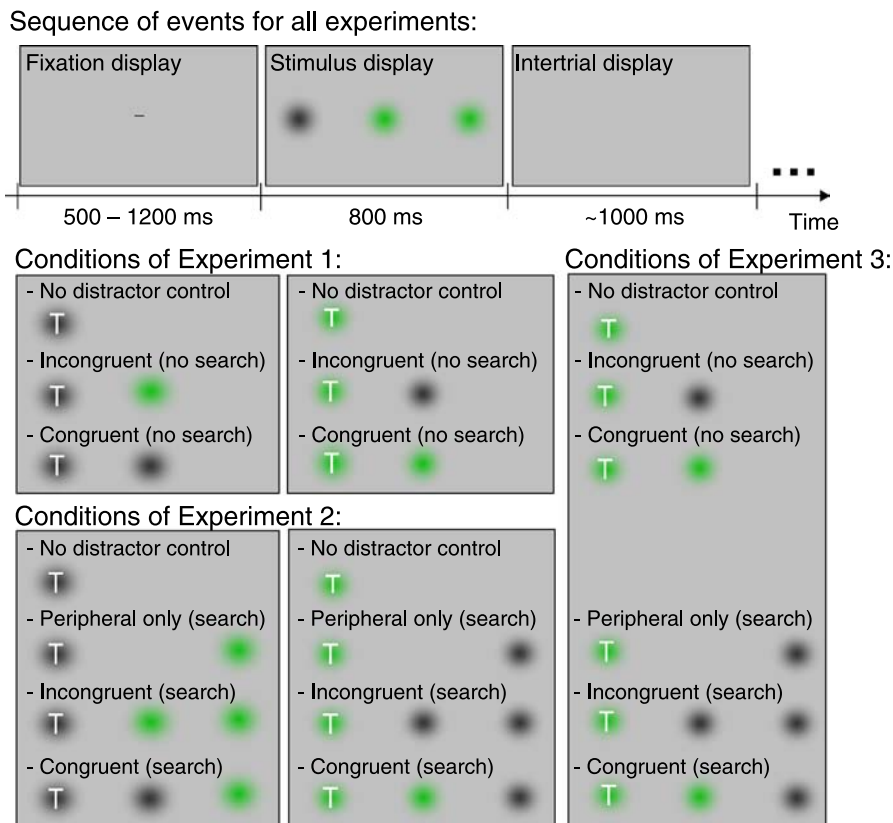


Figure 1. Sequence of events (top) and experimental conditions (bottom) in Experiments 1, 2, and 3. At the beginning of each trial, participants fixated a central fixation line. Upon presentation of the stimulus display, participants had to make a saccade towards the target stimulus as fast as possible. For better understanding, targets are marked by Ts and target direction is held constant (left) in the figure. Note that targets were not marked and target direction was randomized (right, left) in the actual experiment. In Experiment 1, the target property (gray, green) was either randomized or blocked, in Experiment 2 it was always blocked. In Experiment 3, only green targets were used. In search trials the target had to be discriminated from a distractor at the mirror-location by means of its defining property. In no-search conditions, the target can be found by its peripheral location alone.

Figure 2, panels A and B show saccadic latencies for the different distractor conditions and the corresponding no distractor control trials (dotted lines) for the mixed design. Figure 2, panels C and D show the corresponding data of the blocked design. Saccadic latencies in the control trials were found to be longer to green than to gray targets (207 vs. 171 ms), $F(1,11) = 75.53$, $p < .001$. No difference was found between the blocked and the mixed design (188 vs. 189 ms), $F(1,11) = 0.06$.

With respect to the RDE, recall that the effect is defined as the difference between distractor and no distractor control trials. As error bars represent the 95% confidence interval of this difference, the RDE is significantly different from zero if the bars do not cross the dotted line. We conducted a 2 (design: mixed vs. blocked) \times 2 (target property: gray vs. green) \times 2 (target direction: left vs. right) \times 2 (distractor condition: congruent vs. incongruent) repeated-measures ANOVA on the RDE values. The analysis revealed a significant main effect of distractor condition, $F(1,11) = 28.53$, $p < .001$. This main

effect confirms that overall, congruent distractors produced a larger RDE than incongruent distractors. The different size of the RDE in congruent and incongruent conditions will be referred to as congruency effect. Further, there was a significant two-way interaction between design and distractor condition, $F(1,11) = 6.39$, $p = .028$, indicating that the congruency effect was larger in the blocked than in the mixed design (17 vs. 10 ms, respectively; see also Figure 3, panel A). Figure 2 also shows that gray targets produced on average larger congruency effects than green targets (22 vs. 5 ms). Although larger in size, this difference varied more strongly across participants than the difference between blocked and mixed design (gray vs. green target: $SE = 9$ ms; blocked vs. mixed design: $SE = 3$ ms; these errors refer to the standard error of the mean difference in congruency effect). Therefore, the two-way interaction between target property and distractor condition was only marginally significant, $F(1,11) = 3.72$, $p = .080$. Furthermore, the ANOVA revealed a significant two-way interaction

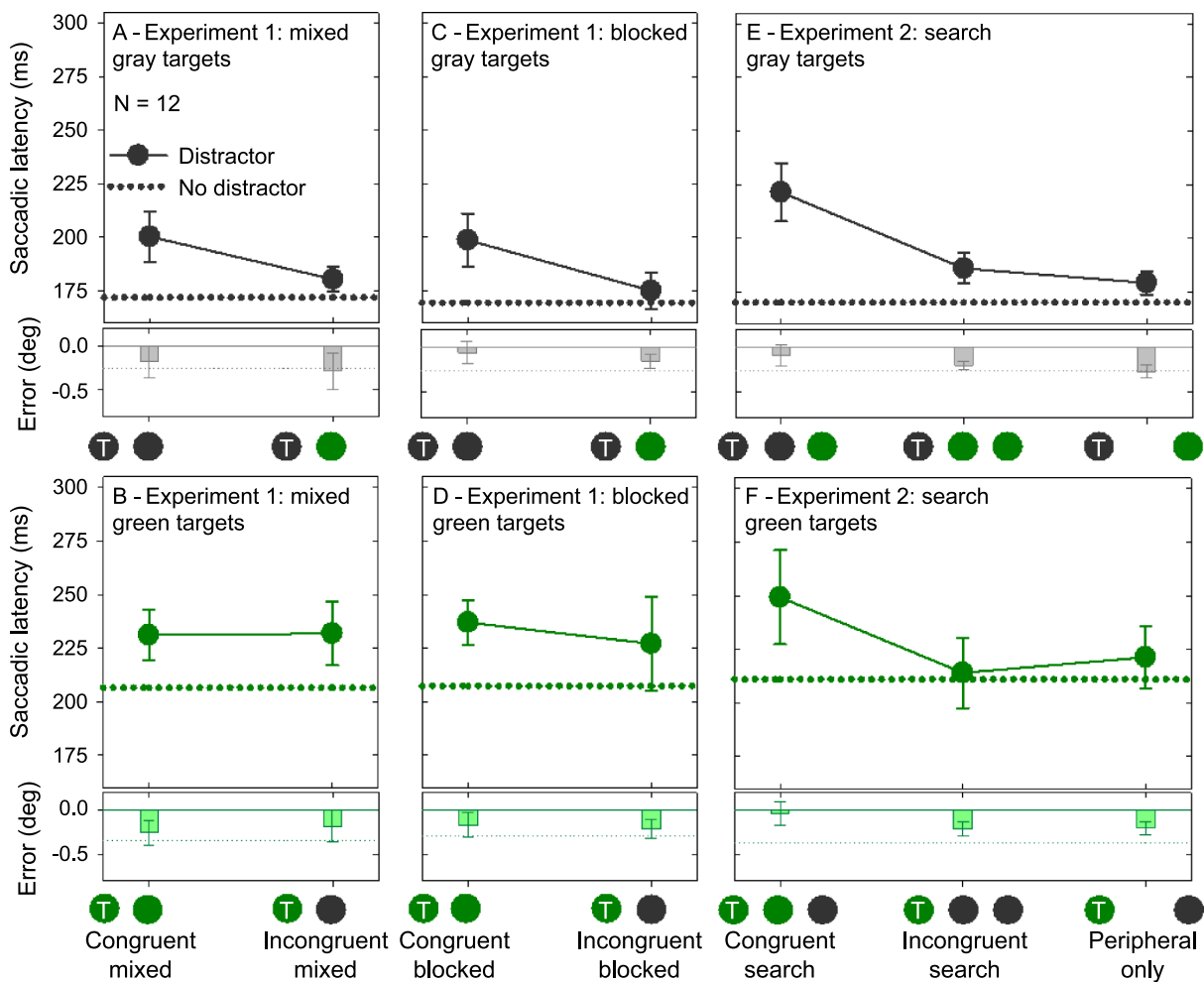


Figure 2. Saccadic latencies (line graphs) and horizontal landing position error (bar charts) as a function of distractor condition in **Experiment 1** (panels A–D) and **Experiment 2** (panels E–F). The dotted lines mark the no distractor control conditions. Error bars represent the 95% confidence interval of the difference between the respective distractor condition and the control condition (i.e. the confidence interval of the remote distractor effect, RDE). If error bars do not cross the line of the control condition, the RDE is significantly different from zero ($p < .05$). All conditions were tested on the same 12 participants.

between target direction and distractor condition, $F(1,11) = 7.94$, $p = .017$, showing larger congruency effects for rightward than for leftward saccades (17 vs. 9 ms). No further effect reached significance.

Additionally, we conducted an intertrial analysis for the results in the mixed design. We compared trials in which the target in the previous trial was the same to those in which it was different. **Figure 3B** illustrates that congruency effects were similar for trials in which the target property was repeated compared to trials in which the target property was switched, $t(11) = 0.31$.

Finally, we checked whether differences in saccade latency were associated with differences in saccade metrics. To this end, we calculated the horizontal deviation of the saccadic landing position from the target's center in degrees of visual angle. Data are shown in the bar charts in the lower part of **Figure 2**, panels A–D. Negative values indicate that saccades fell short of the

target's center. There was no significant effect of distractor condition, $F(1,11) = 2.56$, and no significant two-way interaction between design and distractor condition, $F(1,11) = 1.10$. However, there was a significant two-way interaction between target property and distractor condition, $F(1,11) = 7.70$, $p = .018$ and a three-way interaction between design, target property and distractor condition, $F(1,11) = 4.99$, $p = .047$. Indeed, **Figure 2** suggests that when a congruency effect in the RDE was observed (see panels A, C and D) saccade accuracy was better in the congruent condition, presumably because accuracy increased when subjects responded more slowly.

Discussion

We conjectured that participants would tune their saccadic system to a particular target feature if this feature

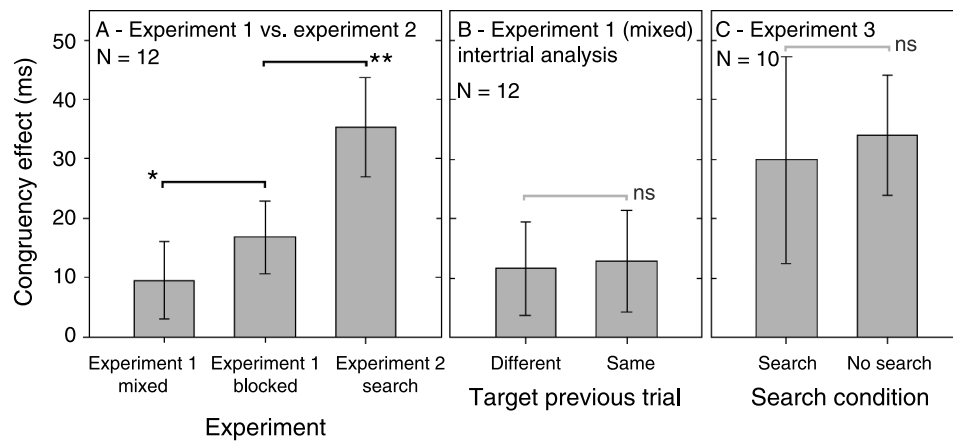


Figure 3. Congruency effects in Experiments 1, 2, and 3. The congruency effect is the difference between the remote distractor effect in congruent and incongruent conditions. *Panel A* shows congruency effects as a function of experimental design and search requirements in Experiments 1 and 2. *Panel B* shows the congruency effect as a function of the target property on the previous trial in the mixed design of Experiment 1. *Panel C* shows the congruency effects for the search and no search condition in Experiment 3. Brackets mark *t*-tests (*: $p < .05$; **: $p < .001$; ns: no significant difference). Error bars represent the 95% confidence interval of the congruency effect. If error bars do not cross the zero line, the congruency effect is significantly different from zero ($p < .05$).

remains constant within a block of trials. In contrast to our hypothesis, congruency effects were found for both the blocked and the mixed design. However, the interaction between design and distractor condition showed that the congruency effect was larger in the blocked design (see also Figure 3A). We interpret this difference as evidence for a top-down modulation of the RDE. In the blocked design, participants knew the property of the upcoming target beforehand. They were able to tune their saccadic system accordingly and as a result, the impact of congruent distractors sharing the target property was enhanced and/or the impact of incongruent distractors was reduced.

Why did we also find a significant congruency effect in the mixed design? Figure 2 clarifies that the congruency effect in the mixed design was largely due to the gray target condition (compare panels A and B). This observation is supported by the marginally significant interaction between target property and distractor condition. We argue that the pattern of results can be explained by bottom-up factors. The RDE is usually considered to reflect competitive processes between the target and the distractor signal in the oculomotor system (e.g. Findlay & Walker, 1999; Godijn & Theeuwes, 2002; Munoz & Fecteau, 2002). Saccadic latencies in the control condition varied with target property: saccades to green targets took around 40 ms longer than to gray targets. This difference might indicate that the strong luminance signals from the gray stimuli arrive earlier in the oculomotor control structures than the signals from the green stimuli (for a review on related findings see Bompas & Sumner, 2008). In the gray target condition, the slower signal of the green distractor arrives too late to compete with the fast signal of the gray target. Therefore, it cannot produce a RDE. In the green target condition, the signals from both the

gray and the green distractors arrive in time to compete with the target signal (see also Born & Kerzel, 2008). Following this line of reasoning we want to stress that a congruency effect as such does not necessarily indicate a top-down influence. It is the finding that the congruency effect was larger in the blocked than in the mixed design that we interpret as an involvement of top-down processes.

Still one could argue that as the target property was repeated throughout a given block, a setting for the target property might have been established automatically, without any voluntary top-down control. It is known that repeating the target property in singleton search tasks speeds up reaction times (Maljkovic & Nakayama, 1994). This effect is supposed to reflect a memory trace that persists up to the subsequent trial and automatically speeds up reaction times if the target property is repeated. Such a memory trace might also enhance the perturbing influence of a congruent distractor in our paradigm. In this case, larger congruency effects would be expected in the mixed design when the target property of the previous trial was repeated, compared to trials where the target property was switched. However, the intertrial analysis showed that repeating the target property did not result in a larger congruency effect (see Figure 3B). Therefore, we assume that a persisting memory trace for the target property cannot account for the differences between the mixed and blocked design in our experiment.

Saccade accuracy data partly mirrored the RDE results consistent with a speed-accuracy trade-off. Discussion of these findings and of the significant effects of target direction is deferred to the General discussion. In sum, we propose that top-down settings are responsible for the different size of the congruency effect in the mixed and the blocked design. Note, however, that despite its

statistical significance the difference was very subtle (around 7 ms). We suppose that blocking the target property was not sufficient to induce strong top-down settings. As the target was the only peripheral stimulus, it could be located without considering its properties. Therefore, participants were not really encouraged to tune their oculomotor system to the target property. Hence, we designed a second experiment in which we tried to maximize top-down modulations of the RDE by introducing a discrimination task.

Experiment 2

Methods

Participants had to make an eye movement to a target of a pre-specified property (gray or green). This property was held constant within a block whereas target direction varied randomly. Importantly, we presented an incongruent distractor opposite to the target on 75% of trials. Thus, to make a correct eye movement, participants had to search for the target. That is, they had to discriminate the target from the peripheral distractor based on its defining property (gray or green). In this context, a top-down setting is necessary to quickly find the target and to avoid incorrect saccades. On some trials, we presented a second irrelevant distractor at the central location that could either be congruent or incongruent with the target property. There was an equal percentage (25% each) of no distractor control trials, trials with only the peripheral distractor, trials with a congruent central distractor, and trials with an incongruent central distractor (see [Figure 1](#)). These conditions were randomly interleaved.

The same fourteen participants that took part in [Experiment 1](#) were recruited for [Experiment 2](#). As [Experiments 1](#) and [2](#) were run around the same time, half the participants first completed [Experiment 2](#), whereas the other half started with [Experiment 1](#). Altogether, [Experiment 2](#) was run in a single session of ~50 min, divided into four blocks of 120 trials: two blocks with gray targets, two blocks with green targets. Half the participants started with the gray, half with the green target blocks. In all other respects (stimuli, equipment and eye movement data analyses), [Experiment 2](#) was identical to [Experiment 1](#).

Results

To allow for within-subjects comparisons, the two participants that were excluded from analyses in [Experiment 1](#) were also excluded in [Experiment 2](#). For the remaining twelve participants, 8.2% of the trials were discarded. Saccadic landing position errors (4.8%), blinks (2.6%) and direction errors (2.0%) were the most frequent errors.

[Figure 2](#), panels E and F show saccadic latencies for the different distractor conditions and the corresponding no distractor control trials. As before, saccadic latencies in the control trials were found to be longer to green than to gray targets (211 vs. 170 ms), $F(1,11) = 71.44$, $p < .001$. The figure also suggests that congruency effects were present for both target properties. We conducted a 2 (target property: gray vs. green) \times 2 (target direction: left vs. right) \times 3 (distractor condition: peripheral only, incongruent, congruent) repeated-measures ANOVA on the RDE values. As expected, there was a significant main effect of distractor condition, $F(2,22) = 56.14$, $p < .001$. Subsequent pairwise t -tests showed that the congruent condition was 35 ms slower than both the incongruent and the peripheral only condition, $t(11) = 9.34$, $p < .001$, and $t(11) = 6.73$, $p < .001$, respectively. There was no significant difference between the peripheral only and the incongruent condition (mean difference of 0.2 ms), $t(11) = 0.15$. Furthermore, there was a significant two-way interaction between target dimension and distractor condition, $F(2,22) = 5.96$, $p = .009$. [Figure 2](#) shows that the congruency effect (i.e., the difference between congruent and incongruent conditions) was similar for both gray and green targets (35 vs. 36 ms), $t(11) = 0.04$. Therefore, the interaction rather stems from differences with respect to the peripheral only condition. Note that for gray targets the incongruent condition produced a larger RDE than the peripheral only condition (16 vs. 9 ms), whereas the RDE was larger in the peripheral only condition for green targets (11 vs. 8 ms). Moreover, there was again a significant two-way interaction between target direction and distractor condition, $F(2,22) = 3.49$, $p = .048$. As in [Experiment 1](#), the overall congruency effect was slightly more pronounced for rightward than for leftward saccades (37 vs. 34 ms). Also, the peripheral only condition showed a slightly larger RDE than the incongruent condition for leftward saccades (11 vs. 8 ms), but a smaller RDE for rightward saccades (9 vs. 11 ms).

We further ran a pairwise t -test, comparing the congruency effects of [Experiment 2](#) with the congruency effects obtained in the blocked design of [Experiment 1](#) ([Figure 3](#), panel A). The congruency effect was larger in [Experiment 2](#) than in [Experiment 1](#), $t(11) = 4.34$, $p = .001$.

Finally, we ran the same three-way ANOVA on the saccade accuracy data. As for the RDE analysis, there was a significant main effect of distractor condition, $F(2,22) = 16.02$, $p < .001$. The lower parts of [Figure 2](#), panels E and F illustrate that the accuracy data mirror the RDE data: the congruent condition produced a smaller horizontal error than the incongruent or the peripheral only condition. No other effects were significant.

Discussion

Substantial congruency effects of 35 ms emerged in [Experiment 2](#). Importantly, these were larger than in [Experiment 1](#). We suggest that the discrimination task was

more efficient to induce a top-down setting than simply blocking the target property. However, there remain some alternative explanations that are linked to the change in the stimulus display. In the congruent and incongruent condition of [Experiment 2](#), there were always three stimuli on the screen: two of the same property and one of the opposite property that “popped out” among the others. Note that in the congruent condition, the peripheral distractor popped out whereas in the incongruent condition the target popped out. Thus, the distractor effect in the congruent condition might actually have been enhanced due to the pop-out of the peripheral distractor. Similarly, the pop-out of the target might have reduced the distractor effect in the incongruent condition. To clarify whether pop-out of the peripheral distractor or other display-specific effects may be responsible for the larger congruency effect in [Experiment 2](#), we conducted a third experiment.

Experiment 3

Methods

In [Experiment 3](#), participants were asked to saccade to a green peripheral stimulus that appeared randomly either to the left or right (no gray targets were used). We included all distractor conditions from [Experiment 2](#) (search conditions) and added conditions with a single central distractor that was either congruent or incongruent (no-search conditions; see [Figure 1](#)). Note that the no-search conditions are identical to the congruent and incongruent distractor conditions in the blocked design of [Experiment 1](#). The only difference is the trial context. In [Experiment 3](#), no-search trials were embedded in search trials that required discrimination of the target from the peripheral distractor based on the target’s defining property. Although the number of distractor conditions was higher in [Experiment 3](#), no distractor control trials made up 25% of trials in a given block and were randomly interleaved with distractor trials. In the remaining 75% of trials, all five distractor conditions were equally frequent and randomly interleaved. If the larger congruency effect in [Experiment 2](#) was solely due to differences in the stimulus display, the congruency effect should be smaller in the no-search trials than in the search trials. If the larger congruency effect was due to an overall stronger top-down setting, then this setting should also apply to the no-search conditions and therefore congruency effects in the search and no-search conditions should be similar. Ten first-year psychology students who had not participated in [Experiments 1](#) and [2](#) took part in [Experiment 3](#). All reported normal or corrected to normal vision and ranged from 18 to 27 years of age. They completed five blocks of 120 trials in a single

experimental session of ~50 min and received course credit for their participation.

Results

Overall, 15.2% of the trials were discarded from analysis. Saccadic landing position errors (8.8%), direction errors (3.2%) and blinks (2.1%) were the most frequent errors.

[Figure 4](#) shows that we obtained a similar congruency effect in the search conditions compared to the no-search conditions. We conducted a 2 (target direction: left vs. right) \times 5 (distractor condition: peripheral only, congruent/search, incongruent/search, congruent/no search, incongruent/no search) repeated-measures ANOVA on the RDE values. It revealed a significant main effect of distractor condition, $F(4,36) = 17.20$, $p < .001$. Subsequently, we directly compared the congruency effect obtained in the no-search conditions with the one obtained in the search conditions. [Figure 3C](#) illustrates that it was slightly larger in the no-search compared to the search conditions (34 vs. 30 ms), but a pairwise t -test revealed that this difference was not significant, $t(9) = 0.59$. Therefore, we next calculated the mean of these two effects as an estimate of the overall congruency effect in [Experiment 3](#). Independent-sample t -tests revealed that this effect of 32 ms was significantly different from the overall congruency effect of 17 ms in the blocked condition of [Experiment 1](#), $t(20) = 2.69$, $p = .014$. However, it was not significantly different from the overall congruency effect of 35 ms in [Experiment 2](#), $t(20) = 0.54$. Furthermore the ANOVA revealed a significant main effect of target direction, indicating that the RDE was larger for rightward (26 ms) than for leftward (15 ms) saccades, $F(1,9) = 7.81$, $p = .021$. No further effect reached significance.

The two-way ANOVA on the saccade accuracy data showed a corresponding main effect of distractor condition, $F(4,36) = 2.69$, $p = .046$. The bar charts in [Figure 4](#) illustrate that accuracy was again slightly better in the congruent conditions. Moreover, there was a significant main effect of target direction, $F(1,9) = 6.83$, $p = .028$, and a significant two-way interaction between target direction and distractor condition, $F(4,36) = 2.93$, $p = .034$, indicating that saccade accuracy was worse and the modulation with distractor condition larger for leftward than for rightward saccades.

Discussion

The congruency effect was as strong for the no-search as for the search conditions. Recall that the stimulus arrangement of the no-search conditions was equivalent to the arrangement in [Experiment 1](#), whereas the arrangement of the search conditions exactly matched those from

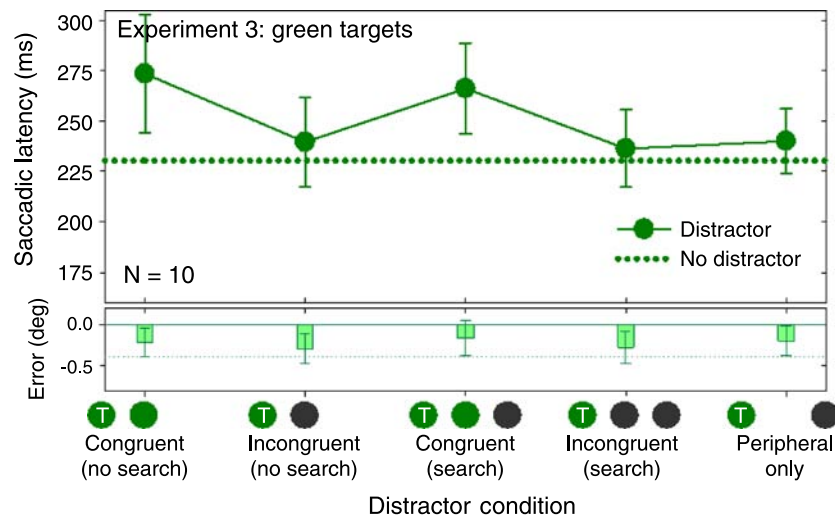


Figure 4. Saccadic latencies (line graphs) and horizontal landing position error (bar charts) as a function of distractor condition in Experiment 3. The dotted line marks the no distractor control condition. Error bars represent the 95% confidence interval of the difference between the respective distractor condition and the control condition (i.e. the confidence interval of the remote distractor effect, RDE). If error bars do not cross the line of the control condition, the RDE is significantly different from zero ($p < .05$). In search trials the target had to be discriminated from a distractor at the opposite location by means of its defining property. In no-search conditions, the target could be identified by its peripheral location alone.

Experiment 2. We conclude that display-specific mechanisms such as pop-out were not responsible for the larger congruency effect in Experiment 2 compared to Experiment 1. We propose that the necessity to discriminate the target from a peripheral distractor in some trials of Experiments 2 and 3 encouraged subjects to adopt a strong top-down setting for the target property. This setting equally influenced the results of search and no-search trials. Note that the overall congruency effects in Experiments 2 and 3 are not significantly different from each other. This indicates that the top-down setting was equally strong. As Experiments 2 and 3 were run with different subjects, this comparison should be interpreted with caution, though.

General discussion

In three experiments we examined congruency effects between target and distractor properties in the RDE. Targets could either be gray or green and distractors could either share the target's defining property (congruent) or be different from the target (incongruent). Larger RDEs for congruent distractors were found in all three experiments. Importantly, these congruency effects were modulated by task demands: the more participants were encouraged to adopt a top-down setting for the target property, the larger the congruency effect. We suggest that

these modulations indicate a top-down influence on the RDE.

Top-down influences on saccadic latency in visual search tasks

Our findings are closely related to previous research using singleton search tasks (Ludwig & Gilchrist, 2002, 2003; Mulckhuyse, van Zoest, & Theeuwes, 2008). In these studies, participants were asked to saccade to a color singleton target that was presented among homogeneously colored distractors. Target and distractor color was held constant, so that participants knew beforehand what target color they were looking for. On some trials, an additional distractor was displayed. This distractor could either be of the same color as the target or of the same color as the other distractors. Distractors that were similar to the target prolonged saccadic latencies more than the dissimilar distractors. The authors interpreted this pattern as a result of top-down control. Our study complements these findings in several ways. First, we showed that low-level pop-out mechanisms are not responsible for the obtained congruency effects. Second, our conclusions are not solely based on the finding of a congruency effect. As we argued above, congruency effects as such might not be evidence for a top-down mechanism. Distinct stimulus properties in the incongruent condition (e.g. a gray target but a green distractor) might provoke differential time delays for the arrival of target and distractor signals in the oculomotor

system (see also Born & Kerzel, 2008). Hence, their ability to compete with each other may be reduced compared to a congruent condition even without a top-down influence. Instead, we varied how strongly task demands encouraged participants to adopt a top-down setting. Because task demands affected congruency effects, we conclude that top-down processes are involved.

Mechanisms of top-down control

One may ask how top-down mechanisms exert their influence. Processing of target properties may be enhanced which would increase the distracting effect of congruent stimuli. Alternatively, non-target properties may be inhibited which would reduce the distracting effect of incongruent stimuli. Unfortunately, our results do not provide a clear answer. Inspection of Figure 2 suggests that there was enhancement of the target property for gray and green targets, because the RDE in the congruent condition was larger with a strong top-down setting (panels E and F) than without top-down setting (panels A and B). In contrast, a strong top-down setting reduced the RDE of incongruent distractors only with green targets (panel F vs. B), but not with gray targets (panel E vs. A). More research is necessary to clarify this issue.

Another interesting result is that we found only small or no RDEs for the incongruent peripheral distractor in the peripheral only conditions of Experiments 2 and 3. This indicates that top-down settings do not only affect the impact of central, but also of peripheral distractors. It is puzzling that some studies reporting a reliable RDE with peripheral distractors also used targets and distractors with different properties (e.g. Benson, 2008; Griffiths et al., 2006; Walker et al., 1997). For instance, Walker et al. (1997) and Griffiths et al. (2006) used crosses as targets, but outline circles as distractors. Why were participants not able to tune themselves to the target property “cross” and in this way reduce the impact of the circle distractor? We propose that the discrepancy may be explained by the nature of the top-down tuning mechanism. Visual search studies suggest that top-down settings are dimension-specific, not feature specific (Meeter & Theeuwes, 2006; Müller, Reimann, & Krummenacher, 2003). The singleton target in a pop-out search task can differ along several perceptual dimensions from its surrounding homogenous distractors. It might, for instance, have a different shape, color, size or orientation. Cuing this dimension before each search trial speeds up manual reaction times. However, cuing the specific feature value of the target (e.g. if it is red or green, left-tilted or right-tilted etc.) does not produce any additional RT benefits (Müller et al., 2003). Meeter and Theeuwes (2006) looked at distractor effects on manual RTs in singleton search. Participants had to report the presence of a specific color or orientation singleton. On some trials, a distractor singleton was

presented that was either congruent or incongruent with the target dimension (color, orientation) but always incongruent with the specific target feature. For instance, if participants looked for a green target singleton in a field of gray distractors, the distractor singleton was either red or tilted. A cue indicated the feature of the upcoming target (e.g. green) with 100% validity. Despite being incongruent with both the target feature and the feature-specific cue, dimension-congruent distractors (e.g. red distractors) produced slower RTs than dimension-incongruent distractors (e.g. tilted distractors). The authors concluded that participants were not able to restrict their setting to the specific target feature. Instead, the cue could only induce a dimensional setting for an unspecific color or an orientation contrast. According to a dimensional account, top-down influences emerged in our experiments because targets and distractors were defined along two independent perceptual dimensions: luminance and color. Participants were able to tune their saccadic system to either one. In contrast, the crosses and squares that were used as target and distractors in previous studies might belong to the same perceptual dimension. Therefore, participants were unable to suppress the RDE of the peripheral distractor that was only feature-incongruent, but dimensionally congruent.

Implications for other work

Sumner, Adamjee, and Mollon (2002) examined whether a peripheral color change only visible to the S-cone pathway can elicit a RDE. Participants were asked to saccade to a small black square that could appear in one of two placeholder boxes to the left or right of a central fixation stimulus. Target onset was masked by luminance noise. They found a RDE when the distractor was a brief increase in luminance in the box opposite to the target. However, no RDE was observed when the opposite box changed from gray to a color in the S-cone range. The authors concluded that the failure to obtain a RDE with a S-cone distractor is consistent with mediation of the effect by low-level pathways, more precisely by a direct retinotectal route from the retina to the superior colliculus or by the magnocellular division of the geniculostriate pathway. Both these routes are considered to be insensitive to S-cone stimulation (de Monasterio, 1978a, 1978b; Marrocco & Li, 1977; Schiller & Malpeli, 1977; Schiller, Malpeli, & Schein, 1979).

While this account may hold, a top-down mechanism can provide an alternative explanation. Note that the target dimension was held constant in their experiment. The saccade target was always a black square. That is, it was defined by a luminance difference to the background. Thus, the lack of a RDE for color distractors might be explained by a top-down setting for a luminance change. According to the dimension-specific account, luminance

decreases and increases should be equally efficient as distractors. Note that a top-down setting for luminance might have been adopted despite the fact that the target could have been easily found by its location alone (target direction was blocked). Rather long mean saccadic latencies in the no distractor control condition (~ 300 ms) indicate that target onset was hard to detect, probably due to the luminance noise. Thus, the difficulty of the task might have induced subjects to adopt a top-down setting for a luminance change. Unfortunately, the study did not include a condition where the target was defined by color. With color-defined targets, a RDE for S-cone distractors might re-emerge because the distractor dimension corresponds to a top-down control setting for a color change.

Speed-accuracy trade-offs and effects of target direction

Our results showed a speed-accuracy trade-off in all three experiments: the larger RDE for congruent distractors was accompanied by more accurate saccades. Previously, Walker et al. (1997) found that saccade accuracy was unaffected by small central distractors. In contrast, other authors report speed-accuracy trade-offs consistent with our data (e.g. McSorley & Findlay, 2003; Vitu, Lancelin, Jean, & Farioli, 2006). McSorley and Findlay (2003) suggested that the increase in latency that is produced by remote distractors can be used by the oculomotor system to “passively” refine saccade metrics. According to them, visual processing is supposed to proceed in a coarse-to-fine manner: the more the initiation of a saccade is delayed, the more accurate the representation of the target location to guide the saccade. Still, they argue that the RDE is unlikely to reflect an “active” or willful delay of saccade initiation to improve accuracy. Along these lines, we do not believe that our participants voluntarily delayed their response selectively in the congruent distractor conditions. Interestingly, such an interpretation may also be regarded as a top-down influence. However, it would have nothing to do with selective enhancement or inhibition of congruent or incongruent signals as proposed above.

Our analyses also revealed occasional effects of target direction. In most cases the respective effects were more pronounced for rightward than for leftward saccades. At the moment, we cannot offer an explanation for these findings. Recall that viewing conditions were binocular in our experiments. Therefore, there is no link to previously found effects of naso-temporal asymmetry in the RDE or in saccadic choice behavior (Bompas, Sterling, Rafal, & Sumner, 2008; Walker, Mannan, Maurer, Pambakian, & Kennard, 2000). Whatever the reasons for the effects of target direction, we think that they do not challenge our main conclusions.

Conclusions

In conclusion, we suggest that the RDE can be modulated in a top-down manner. This modulation strongly depends on task demands, though. Without a strong incentive to adopt a top-down setting, top-down influences will be minimal. Future research may examine the exact mechanism of the top-down modulation. For instance, one may investigate whether enhancement of congruent signals or inhibition of incongruent signals is prevalent.

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Footnote

¹Findlay and Walker (1999; see also Walker et al., 1997) discussed mutual inhibition between a “fixate centre” (or “fixation zone”) and an opposed “move centre” (representing targets in the periphery). However, the important point is that the authors assume that the perturbing influence of both central and peripheral distractors is mediated by an activation of the “fixate centre” whose connections may extend up to 10° of visual angle into the periphery.

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