

A global effect of capture saccades

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Received: 1 November 2010 / Accepted: 12 February 2011 / Published online: 4 March 2011
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Abstract When two target elements are presented in close proximity, the endpoint of a saccade is generally positioned at an intermediate location ('global effect'). Here, we investigated whether the global effect also occurs for eye movements executed to distracting elements. To this end, we adapted the oculomotor capture paradigm such that on a subset of trials, two distractors were presented. When the two distractors were closely aligned, erroneous eye movements were initiated to a location in between the two distractors. Even though to a lesser extent, this effect was also present when the two distractors were presented further apart. In a second experiment, we investigated the global effect for eye movements in the presence of two targets. A strong global effect was observed when two targets were presented closely aligned, while this effect was absent when the targets were further apart. This study shows that there is a global effect when saccades are captured by distractors. This 'capture global' effect is different from the traditional global effect that occurs when two targets are presented because the global effect of capture saccades also occurs for remote elements. The spatial dynamics of this global effect will be explained in terms of the population coding theory.

Keywords Eye movements · Global effect · Oculomotor capture · Saccades

Introduction

In order to explore our environment, we continuously make fast eye movements called saccades. The endpoint of a saccade to a target element is known to be influenced by the presence of other elements in the visual scene. For instance, when two elements are presented in close proximity, the saccadic endpoint will be positioned at an intermediate location (Coren and Hoenig 1972). This phenomenon, known as the 'global effect', occurs only when both elements are presented within 20–30° of angular distance (Walker et al. 1997). The global effect is considered a reflexive (bottom-up) event, because it only occurs for the shortest latencies of the latency distribution (Ottes et al. 1985; Godijn and Theeuwes 2002) and is modulated by low-level factors as luminance and size (Findlay 1982; Deubel et al. 1984).

The global effect is generally explained in terms of the 'center of gravity account', which states that the saccadic endpoint is based on the relative saliency of different elements in the saccade map (Coren and Hoenig 1972). When the distance between two elements is small, the average saliency will be located in between these two elements. This explanation is in line with the population coding theory of Tipper et al. (1997, 2000). This theory states that each neuron in a motor map codes an individual vector that encodes the movement toward the corresponding location. It is assumed that a movement program results in activation of a broad population of vectors. Eye movements are initiated in the direction of the average of the vectors present in the oculomotor system. When two elements are presented simultaneously in close proximity, the average movement vector will point to an intermediate location. The resulting eye movement will therefore reflect an average of the eye movements to both elements.

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In most previous studies on the global effect, participants had to execute an eye movement to a target element that elicited the global effect (e.g., He and Kowler 1989; Van der Stigchel et al. 2010). The present study investigates whether the global effect also occurs for eye movements executed to nontarget elements, i.e., to distractor elements. To this end, we used the oculomotor capture paradigm (Theeuwes et al. 1998, 1999), in which the task of the participant is to make an eye movement to a target circle with a unique color. In half of the trials, an additional circle is presented with abrupt onset ('distractor'). On a large portion of trials, participants are unable to inhibit an eye movement to the location of the distractor before executing a saccade to the target ('capture saccades'). Erroneous saccades in the oculomotor capture paradigm are dominantly reflexive, because the distractor does not need to be attended in order to successfully perform the task. Moreover, there is no explicit task instruction to ignore the distractor. The distractor is therefore task-irrelevant (Godijn and Kramer 2006; Van der Stigchel 2010).

It is currently unclear whether a global effect can be elicited by capture saccades. One previous study that investigated the effect of multiple distractors on performance in the oculomotor capture task revealed little evidence for a global effect for capture saccades when two distractors were presented (Kramer et al. 2001). There was no global effect in a first experiment, and only a small effect in a second experiment in which the timing of presentation of the two distractors was manipulated. Moreover, no effect of the distance between the two distractors on the global effect was observed, which is inconsistent with previous studies that the global effect is only observed when both elements are presented within 20–30° of angular distance (Walker et al. 1997). It has to be noted that the analyses of the endpoint shift of capture saccades was somewhat limited, because it was limited to capture saccades which were executed to the actual centre of the two distractors, instead of a detailed analysis of the endpoint shift.

In the present study, the first experiment was designed to investigate the endpoint shift of capture saccades in detail by using a variation of the oculomotor capture task in which a high level of capture is expected. To measure the global effect of capture saccades, the oculomotor capture paradigm was adapted such that two distractors were presented in a portion of the trials. The distance between the two distractors was varied to study the spatial dynamics of the endpoint shift of capture saccades. Furthermore, the color of the distractor was the same as the color of the target element. Due to the increased similarity between target and distractor, the percentage capture saccades will be higher compared to the original version of the oculomotor capture paradigm in which the color of the distractor

was the same as the non-targets (Mulckhuysen et al. 2008). To study the endpoint shift of capture saccades in detail, a high percentage of capture trials was required.

Besides studying the endpoint shift evoked by the presence of two distractors, this paradigm also allowed to investigate whether the percentage capture saccades is influenced by the presence of a second distractor. Considering the biased competition account (Desimone and Duncan 1995), the unique bottom-up signal evoked by a single distractor is assumed to be less strong when an additional distractor is present, compared to when the distractor is the sole bottom-up signal. Similar to the findings by Kramer et al. (2001), we therefore predict that the percentage capture will be lower when two distractors are presented compared to when one distractor is presented.

Experiment 1

Methods

Subjects

A total of ten participants (19–25 years old), all naive to the purpose of the experiment, participated in the experiment. Four of the participants were men. All had normal or corrected-to-normal visual acuity. Informed consent was obtained prior to the study in accordance with the guidelines of the Helsinki Declaration.

Apparatus

Participants performed the experiment in a sound-attenuated setting, viewing a display monitor from a distance of 57 cm. Eye movements were recorded by an Eyelink 1000 system (SR Research Ltd, Canada), an infrared video-based eye tracker that has a 1,000 Hz temporal resolution and a spatial resolution of 0.01°. The participant's head was stabilized with a chin rest, and an infrared remote tracking system compensated for any residual head motion. The left eye was monitored. An eye movement was considered a saccade when either eye velocity exceeded 35°/s or eye acceleration exceeded 9,500°/s².

Stimuli and design

Participants viewed a display containing a gray plus sign (1.0 × 1.0°) on a black background in the centre of the display, which was used as fixation point. Eight green circles (1.8° in diameter) were positioned on an imaginary circle around central fixation point with a radius of 11.7° at 0, 45, 90, 135, 180, 225, 270, and 315 degrees (0 degrees being the top position). After 400 ms, all circles, except

one, changed color to red. The remaining green circle was the target circle. This target circle was either located at 45, 135, 225, or 315 degrees on the imaginary circle. The fixation point was removed 200 ms before target onset.

There were three different conditions (see Fig. 1). In one-third of the trials, there was no distractor presented. In one-third of the trials, an additional green square ($1.5 \times 1.5^\circ$) was presented simultaneously with the target presentation on the same imaginary circle as the other circles ('distractor'). The distractor was always positioned in the opposite hemifield to the target at a fixed position. When the target was presented in the right visual field, the distractor was presented at either 202.5, 247.5, 292.5, or 337.5 degrees. When the target was presented in the left visual field, the distractor was presented at either 22.5, 67.5, 112.5, or 157.5 degrees. In one-third of the trials, two additional distractors were presented simultaneously with the target presentation on the same imaginary circle as the other circles. The distractors were always positioned in the opposite hemifield to the target at fixed positions. When the target was presented in the right visual field, the distractors were either presented at 202.5 and 337.5 degrees (far distractors) or at 247.5 and 292.5 degrees (close distractors). When the target was presented in the left visual field, the distractors were either presented at 22.5 and 157.5 degrees (far double distractors) or at 67.5 and 112.5 degrees (close double distractors).

The target display was presented for 1,200 ms. Afterward all objects were removed from the display.

Procedure

Participants were instructed to fixate the center fixation point until the target appeared, when they were to move

their eyes to the target. Each session started with a nine-point grid calibration procedure. In addition, simultaneously fixating the center fixation point and pressing the space bar recalibrated the system by zeroing the offset of the measuring device at the start of each trial. The sequence of trials was randomized. The experiment consisted of 720 experimental trials and 24 practice trials. Participants heard a warning sound when they made an eye movement before the stimulus target appeared or when saccade latency was longer than 500 ms.

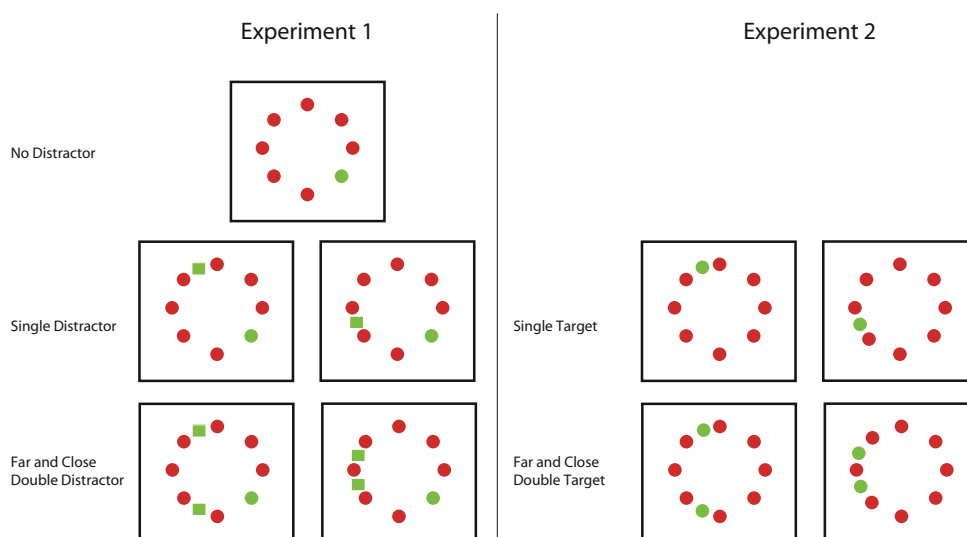
Data analysis

When the endpoint of a saccade was within 5.4° of the target, it was classified as landed on the target. Saccade latency was defined as the interval between target onset and the initiation of the eye movement. Trials were excluded when the latency of the saccade was shorter than 50 ms or longer than 500 ms. Moreover, trials were excluded from analysis when a saccade larger than 2° was made before the onset of the target. The exclusion criteria led to a loss of 4.4% of trials.

For saccade latencies, an Analysis of Variance (ANOVA) was run with Condition (no distractor, single distractor, double distractor) as a factor. Post-hoc *t* tests were used to compare the different conditions.

A capture trial was defined as a trial in the distractor condition in which a saccade landed on the distractor before landing on the target. Saccades were classified as landed on the distractor when the endpoint of a saccade was within 5.4° of the distractor. An ANOVA with Condition (single distractor, close double distractor, far double distractor) as a factor was run. Post-hoc *t* tests were used to compare the different conditions.

Fig. 1 *Left* the different conditions of Experiment 1. In one-third of the trials, no distractor was presented. In one-third of the trials, a single distractor was presented in the opposite visual field of the target. In the remaining trials, two distractors were presented, also in the opposite visual field of the target. The distance between the two distractors was varied. *Right* the different conditions of Experiment 2. In half of the trials, one target was presented, while two targets were presented in the other half of the trials



To investigate the effect of the distance between the distractors on the landing position of capture saccades, we first created a smoothed heatmap of the endpoints of capture saccades in the different conditions (see Fig. 2). As can be seen in Fig. 2, the endpoints of capture saccades

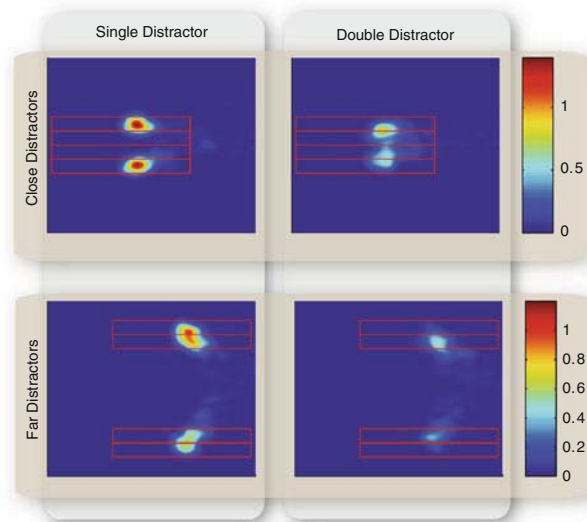
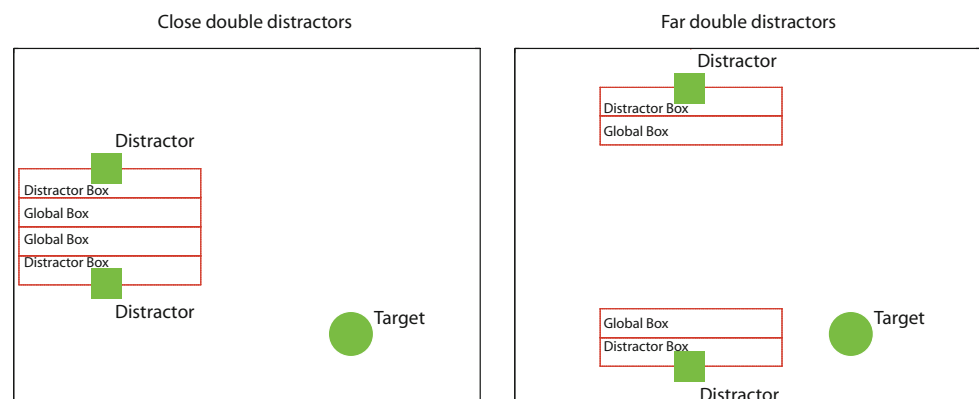


Fig. 2 Illustrations of the endpoints of capture saccades for the four distractor conditions. For each condition, a heatmap was created by convolving a pixel image with a Gaussian kernel ($\sigma = 0.25^\circ$). The image was divided in regions of five-by-five pixels, and the capture saccades (reoriented to always have the target in the *lower right corner*) were classified for all observers accordingly. Following this classification, the image was smoothed to create the heatmap. Only the field containing the distractors is visible in the figure. See Fig. 3 for an illustration of the configuration of target and distractors. The *left column* contains the heatmaps for the single distractor; the *right column* contains the heatmap for the condition with double distractors. The *upper row* shows the conditions in which distractors were presented close together, the *bottom row* shows the conditions in which the distractors were presented far apart. It can clearly be seen that the mean endpoint of capture saccades is shifted to an intermediate location when two distractors are presented closely aligned

are shifted to an intermediate location when two distractors are presented closely aligned. On the basis of Fig. 2, we created areas in which the capture saccades could land. Because we wanted to compare the number of eye movements falling in between the two distractors, the region between the center of each of the two close distractors was divided in four areas. These four areas were equally large ($14.4 \times 2.2^\circ$) for each condition to enable an adequate comparison between the different conditions. The size of the areas was chosen such that it would compass the majority of the capture saccades as illustrated in Fig. 2. See Fig. 3 for an illustration of the various boxes. The two boxes adjacent to the centre of the distractors were named the *distractor boxes*. The two boxes in between the two distractor boxes were named the *global boxes*.

We compared the number of capture eye movements falling in the distractor boxes to the number of capture eye movements falling in the global boxes. To account for differences in the amount of capture between the single and the double distractor condition, the proportion of eye movements that landed in the global box was computed for each condition ($\text{global box}/(\text{global box} + \text{distractor box})$). Subsequently, we subtracted the proportions for the double distractor condition from the single distractor condition for each possible distractor position. Therefore, the comparison of the double distractor condition with the single distractor condition involves the distractor presented at the same location as the one from a pair that is under consideration. This was done to account for possible idiosyncrasies in endpoint patterns. The resulting values for the close double distractor and far double distractor conditions were compared to zero using a *t* test to analyze whether more capture saccades landed in the global effect box compared to the single distractor condition. Furthermore, these two values were compared to each other using a *t* test to analyze whether more capture saccades landed in between the two distractors in the close double distractor condition compared to the far double distractor condition. Finally, we analyzed saccade latencies for the distractor and the global

Fig. 3 Positions of the boxes used in the analyses, reoriented to always have the target in the *lower right corner*. The *distractor boxes* are adjacent to the centre of the distractors, whereas the *global boxes* are located in between the two distractor boxes



box to investigate the temporal dynamics of capture saccade initiation.

Results

Saccade latency

We examined saccade latencies for saccades directed to the target. An ANOVA with Condition (no distractor, single distractor, double distractor) as a factor revealed a main effect ($F(2,18) = 68.974$; $P < 0.0001$). Saccade latencies in the no distractor condition (mean = 260 ms; SD = 23 ms) were significantly shorter than when a single distractor was presented (mean = 288 ms; SD = 24 ms; $t(9) = 9.62$; $P < 0.0001$) and when double distractors were presented (mean = 283 ms; SD = 28 ms; $t(9) = 8.43$; $P < 0.0001$). Furthermore, saccade latency in trials with one distractor was significantly longer than trials in which double distractors were presented ($t(9) = 2.44$; $P < 0.05$).

For trials with a single distractor, latencies for saccades directed to the distractor were shorter (mean = 211 ms; SD = 18 ms) than for saccades that were directed to the target (mean = 288 ms; SD = 24 ms; $t(9) = 22.35$; $P < 0.0001$). Also for trials with double distractors, latencies for saccades to one of the distractors were shorter (mean = 220 ms; SD = 22 ms) than saccades that were directed to the target (mean = 283 ms; SD = 28 ms; $t(9) = 9.81$; $P < 0.0001$). In trials with a single distractor, latencies for saccades to the distractor were significantly shorter than in trials with double distractors ($t(9) = 2.70$; $P < 0.05$).

Saccade latencies for the distractor and the global box

For the close double distractor condition, there was no difference in saccade latencies for the global box and the distractor box ($t(9) = 0.58$; $P = 0.58$). This effect was also absent for the far double distractor condition ($t(9) = 0.82$; $P = 0.43$).

Oculomotor capture

An ANOVA with Condition (single distractor, close double distractor, far double distractor) as a factor revealed a main effect ($F(2,18) = 20.304$; $P < 0.001$). In trials with one distractor, percentage oculomotor capture was higher (mean = 49%; SD = 19%) than when close double distractors were presented (mean = 38%; SD = 21%; $t(9) = 2.90$; $P < 0.02$) and when far double distractors were presented (mean = 25%; SD = 11%; $t(9) = 6.90$; $P < 0.0001$). Furthermore, trials with close double distractors

showed a higher percentage oculomotor capture than trials with far double distractors ($t(9) = 3.22$; $P < 0.02$).

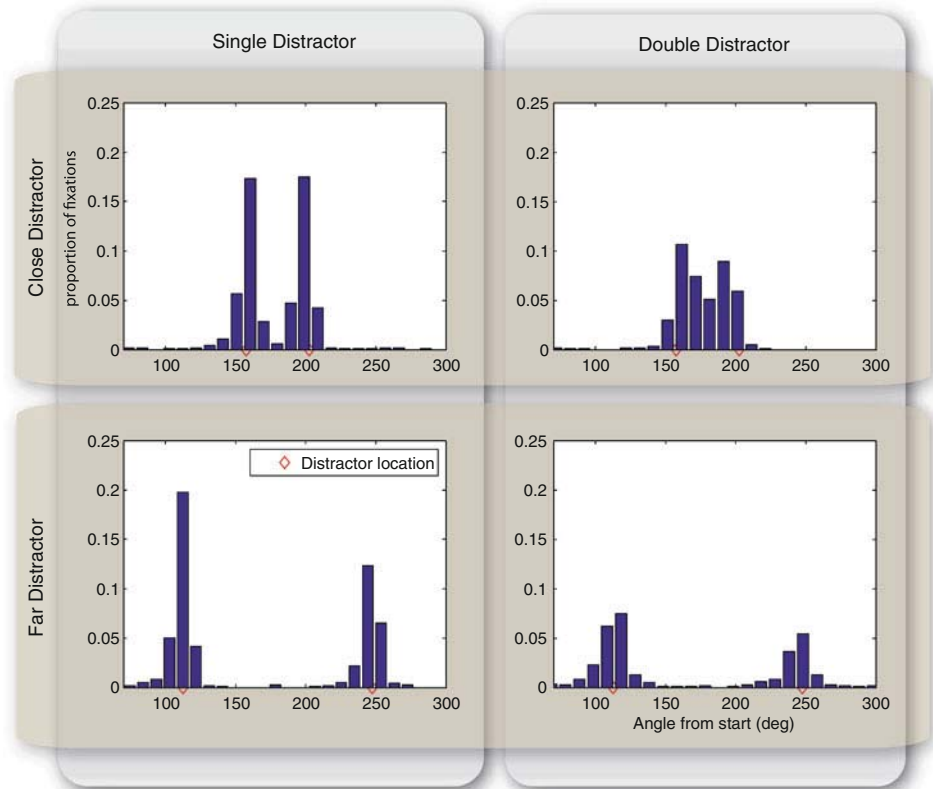
Landing position of capture trials

See Fig. 4 for a one-dimensional distribution of the direction of capture saccades for the different conditions. As explained in the analysis section, we computed the proportion trials that landed in the global box (see Fig. 3). We corrected for the baseline landing position as observed in the single distractor condition by subtracting the proportions for the double distractor condition from the single distractor condition for each possible distractor position. The resulting values for the close double distractor (mean = 35%; SD = 18%) and far double distractor conditions (mean = 17%; SD = 12%) differed significantly from zero (close: $t(9) = 6.18$; $P < 0.001$; far: $t(9) = 4.49$; $P < 0.01$). This indicates that for both double distractor conditions, more capture saccades landed in the global box compared to the single distractor condition. However, a subsequent *t* test showed that this effect was larger in the close double distractor condition compared to the far double distractor condition ($t(9) = 2.74$; $P < 0.03$).

Discussion experiment 1

Experiment 1 investigated the shift of the endpoint of capture saccades executed in the presence of two distractors. The oculomotor capture paradigm was adapted such that two onset distractors were presented on a subset of trials. Results showed that capture saccades evoked by double distractors tended to land on a position in between the two distractors, revealing a global effect of capture saccades. Importantly, even though the shift in endpoint was less strong compared to when two distractors were presented closely aligned, there was a significant shift in endpoint also in the condition in which the distractors were presented far apart. This seems to be inconsistent with the idea that endpoint shifts only occur when both elements are presented within 20–30° of angular distance (Walker et al. 1997). To investigate whether this shift of endpoint evoked by a remote element is restricted to saccades that are captured by onset distractors, we ran a second experiment in which we presented either one or two targets. Similar to Experiment 1, the elements were presented with abrupt onset. This set-up enabled us to unravel whether the shift of endpoint also occurs when an eye movement is made in the presence of two remote targets.

Fig. 4 One-dimensional distribution of the direction of capture saccades for the different conditions



Experiment 2

Methods

Subjects

A total of ten participants (21–37 years old), all naive to the purpose of the experiment, participated in the experiment. Five of the participants were men.

Apparatus, stimuli, and design

The same experimental set-up as Experiment 1 was used. In Experiment 2, no distractor was presented, but one or two targets appeared 400 ms after the eight green circles were presented. The possible locations at which the target could appear were the same as the distractor locations in Experiment 1. In half of the trials, one target was presented, while two targets were presented in the other half of the trials. See Fig. 1 for an illustration of the various conditions.

Procedure

Participants were instructed to fixate the center fixation point until the target appeared, when they were to move

their eyes to the target. In case of two targets, they were instructed to make an eye movement to one of the targets. The experiment consisted of 480 experimental trials and 16 practice trials.

Data analysis

The same criteria were used as in Experiment 1. The exclusion criteria led to a loss of 6.4% of trials.

For saccade latencies, an Analysis of Variance (ANOVA) was run with Condition (single target, close double target, far double target) as a factor. Post-hoc *t* tests were used to compare the two conditions.

To investigate the effect of the distance between the targets on the landing position of saccades, we used the same criteria as in Experiment 1. The two boxes adjacent to the centre of the targets were named the *target boxes*. The two boxes in between the two target boxes were named the *global boxes*. The resulting values for the close double target and far double target conditions were compared to zero using a *t* test to analyze whether more saccades landed in the global effect box compared to the single target condition. Furthermore, these two values were compared to each other using a *t* test to analyze whether more saccades landed in between the two targets in the close double target condition compared to the far double target condition.

Results

Saccade latency

We examined saccade latencies for saccades directed to the target. An ANOVA with Condition (single target, close double target, far double target) as a factor revealed a main effect ($F(2,18) = 33.595$; $P < 0.0001$). Saccade latencies in the condition in which far double targets were presented (mean = 259 ms; SD = 42 ms) were significantly longer than when a single target was presented (mean = 236 ms; SD = 41 ms; $t(9) = 6.20$; $P < 0.001$) and when close double targets were presented (mean = 235 ms; SD = 45 ms; $t(9) = 7.62$; $P < 0.001$).

Landing position of capture trials

See Fig. 5 for the one-dimensional distribution of the direction of the saccades in the different conditions and the smoothed heatmap of the endpoints of the saccades. Similar to Experiment 1, we computed the proportion trials that landed in the target box and corrected for the baseline landing position as observed in the single target condition. The resulting values for the close double targets differed significantly from zero (mean = 27%; SD = 14%; $t(9) = 6.06$; $P < 0.001$). This effect was absent for the far double target conditions (mean = -5%; SD = 10%; $t(9) = -1.56$; $P = 0.15$). This indicates that only for the close double target conditions, more saccades landed in the global box compared to the single target condition. A subsequent t test indeed showed that this effect was

larger in the close double target condition compared to the far double target condition ($t(9) = 7.52$; $P < 0.0001$).

Discussion experiment 2

In Experiment 2, participants made an eye movement in the presence of either one or two targets. Results showed that the eye movement landed in between the two targets when the targets were presented closely aligned. In contrast to Experiment 1, this effect was absent when two remote targets were presented. These results are in line with the idea that endpoint shifts only occur when both elements are presented within 20–30° of angular distance (Walker et al. 1997).

Saccade latency was higher for two remote targets than when two targets were presented that were closely aligned. Moreover, saccade latency for close targets was similar to the condition in which only one target was presented. This illustrates that two close elements might be treated by the oculomotor system as one object. When two remote targets are presented, the oculomotor system has to select one of the targets as the goal of the eye movement. This selection process takes time, which accounts for the observed increase in saccade latency.

General discussion

The present study investigated whether a global effect can also be observed in erroneous eye movements toward distractors. In Experiment 1, the oculomotor capture

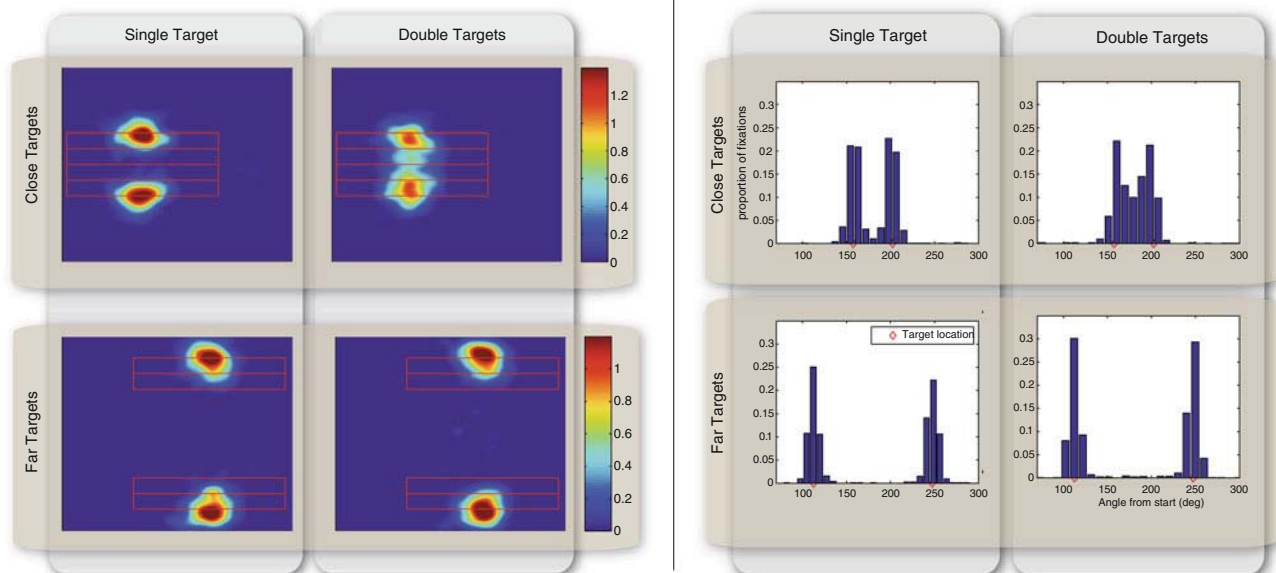


Fig. 5 *Left* smoothed heatmap of the endpoints of the saccades in the different conditions. *Right* one-dimensional distribution of the direction of the saccades executed in Experiment 2

paradigm was adapted such that two onset distractors were presented on a subset of trials. Results showed that capture saccades evoked by double distractors tended to land on a position in between the two distractors, revealing a global effect of capture saccades. Because the color of the onset distractor(s) was equal to the color of the target element (Mulckhuyse et al. 2008), a high percentage of capture was observed (>25%).

The present results with respect to the global effect of capture saccades might seem inconsistent with the study by Kramer et al. (2001) who did not observe a consistent global effect of capture saccades. However, there are a number of differences between the two studies that may explain the differences in results. First, in the present study, the onset distractor(s) had the same color as the target which resulted in an increased number of capture saccades, allowing a more detailed analysis of endpoint shifts of capture saccades. Second, our analyses did not only focus on the centre location between the two distractors but also on a more subtle endpoint shifts toward one of the two distractors. As can be seen in Fig. 3, the endpoint was not always positioned exactly in between the two elements but was sometimes slightly shifted toward the other distractor (especially when the distance between the two distractors was large). Therefore, a more detailed analysis was required to reveal the endpoint shift evoked by an additional distractor.

The observed global effect for saccades that are captured by the distractors is in line with the population coding theory of Tipper et al. (1997, 2000). As noted, this theory states that eye movements are initiated in the direction of the average of the vectors present in the oculomotor system. The present results show that the population coding theory also holds for the averaging of capture saccades. Only in a subset of trials, however, the endpoint was positioned exactly in between the two distractors. In the majority of the trials, the endpoint was still predominantly positioned close to one of the two elements and shifted toward the other element. This was also the case in Experiment 2, in which participants had to execute an eye movement to a target which was accompanied by an additional target in half of the trials. It has to be noted that within each experiment, both elements had equal importance for the task, providing no a priori reason to select one of the two elements. This observation indicates that the merging of the eye movement programs that underlies a completely 'averaged' saccade is restricted to a limited number of trials. In the majority of the trials, one of the elicited vectors will be relatively stronger than the other vector. The subtle shift of saccade endpoint in these trials can then be attributed to residual activity of the other vector.

Our results are inconsistent with the idea that the endpoint shift only occurs when both elements are presented

within 20–30° of angular distance (Walker et al. 1997). Although the global effect was strongest when the distractors were presented closely aligned, there was a small but consistent shift of saccade endpoint in the condition in which two distractors were presented further apart. The observation that elements need to be presented within a restricted zone for averaging to occur was made in a study in which participants made a voluntary eye movement to a target element (Walker et al. 1997). It is therefore possible that the averaging of remote distractors only occurs for involuntary eye movements, like capture saccades. Experiment 2 investigated the global effect for eye movements in the presence of two targets. Again, a strong global effect was observed when the distance between the two targets was small. In contrast to Experiment 1, however, no shift in saccade endpoint was observed when the two targets were presented further apart.

On the basis of the results of the two experiments, it seems that the global effect that occurs for saccades which are captured by onset distractors is different from the traditional global effect, because it spreads over a much larger extend (i.e., when distractors are presented relatively far apart). This difference might be due to the fact that saccades that are captured by distractors are basically involuntary, because they constitute of eye movements that are erroneously made to a distracting element. It is known that these eye movements are executed on the basis of bottom-up information (Theeuwes et al. 1998) and are not under top-down control. In Experiment 2, eye movements were at least partly under top-down control, because they were executed on the basis of the instruction to execute an eye movement to either one of the target elements. In terms of the population coding theory, this may indicate that when two targets are presented simultaneously, the detection of either one of the targets may allow a fast engagement of top-down spatial control, blocking out the vector associated with the remote target but not when the target elements are relatively close to each other. This idea is consistent with a recent study by Belopolsky and Theeuwes (2010) Belopolsky et al. (2007) which showed that the extent to which observers spread their attention across the visual field (the so-called attentional window) determines whether irrelevant events capture our attention. When attention is spread, there is capture across the visual field. When attention is relatively focused there is only capture within the attended area. It is likely that in Experiment 1 there is no opportunity to focus attention, because the detection of a distractor does not allow an engagement of top-down spatial control. This causes bottom-up signals across the visual display to capture attention and affect the eye movement program. In Experiment 2, the detection of any one of the targets allows a fast focusing of attention onto a restricted area blocking out the effect of signals presented outside but not within the focused attentional window.

Consistent with the findings of Kramer et al. (2001), the percentage capture in Experiment 1 was higher in the condition with one distractor compared to the condition with two distractors. This result is in line with the biased competition account (Desimone and Duncan 1995), because the unique bottom-up signal evoked by a single distractor is less strong when an additional distractor is present, compared to when the distractor is the sole bottom-up signal. Interestingly, the stronger bottom-up signal when a distractor is the sole bottom-up signal resulted in capture saccades with a shorter latency than when an additional distractor was presented. This indicates that the strength of a bottom-up signal can influence the speed of the evoked reflex, as revealed by the latency of the capture saccade.

Furthermore, when two distractors were presented closely aligned, the percentage capture saccades was higher than when the two distractors were presented further apart. This finding can be explained by the idea that the two objects are regarded as one signal when they are presented in close proximity. In this situation, the two elements might be treated by the oculomotor system as one object. Indeed, in situations in which the global effect occurs, neural activity in the important motor map in the midbrain, the superior colliculus, has been found to be highest at a location in between the two targets (Van Opstal and Van Gisbergen 1990; Glimcher and Sparks 1993) (but see Edelman and Keller 1998). The finding that the percentage of capture was higher when one distractor was presented compared to when two distractors were presented closely aligned indicates that this only occurs to a certain degree.

Acknowledgments This research was funded by a grant from NWO (Netherlands organization for Scientific Research), grant 451-09-019 to SvdS.

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References

- Belopolsky AV, Theeuwes J (2010) No capture outside the attentional window. *Vis Res* 50:2543–2550
- Belopolsky AV, Zwaan L, Theeuwes J, Kramer AF (2007) The size of an attentional window modulates attentional capture by color singletons. *Psychon Bull Rev* 14:934–938

- Coren S, Hoenig P (1972) Effect of non-target stimuli on the length of voluntary saccades. *Percept Mot Skills* 34:499–508
- Desimone R, Duncan J (1995) Neural mechanisms of selective visual attention. *Ann Rev Neurosci* 18:193–222
- Deubel H, Wolf W, Hauske M (1984) The evaluation of the oculomotor error signal. In: Gale AG, Johnson FW (eds) *Theoretical and applied aspects of oculomotor research*. Elsevier, Amsterdam
- Edelman JA, Keller EL (1998) Dependence on target configuration of express saccade-related activity in the primate superior colliculus. *J Neurophysiol* 80:1407–1426
- Findlay JM (1982) Global visual processing for saccadic eye movements. *Vis Res* 22:1033–1045
- Glimcher PW, Sparks DL (1993) Representation of averaging saccades in the superior colliculus of the monkey. *Exp Brain Res* 95:429–435
- Godijn R, Kramer AF (2006) Prosaccades and antisaccades to onsets and color singletons: evidence that erroneous prosaccades are not reflexive. *Exp Brain Res* 172:439–448
- Godijn R, Theeuwes J (2002) Programming of endogenous and exogenous saccades: evidence for a competitive integration model. *J Exp Psychol Hum Percept Perform* 28:1039–1054
- He P, Kowler E (1989) The role of location probability in the programming of saccades: Implications for “center-of-gravity” tendencies. *Vis Res* 29:1165–1181
- Kramer AF, Cassavaugh ND, Irwin DE, Peterson MS, Hahn S (2001) Influence of single and multiple onset distractors on visual search for singleton targets. *Percept Psychophys* 63:952–968
- Mulckhuysse M, Van Zoest W, Theeuwes J (2008) Capture of the eyes by relevant and irrelevant onsets. *Exp Brain Res* 186:225–235
- Ottes FB, Van Gisbergen JAM, Eggermont JJ (1985) Latency dependence of colour-based target vs nontarget discrimination by the saccadic system. *Vis Res* 25:849–862
- Theeuwes J, Kramer AF, Hahn S, Irwin DE (1998) Our eyes do not always go where we want them to go: capture of eyes by new objects. *Psychol Sci* 9:379–385
- Theeuwes J, Kramer AF, Hahn S, Irwin DE, Zelinsky GJ (1999) Influence of attentional capture on oculomotor control. *J Exp Psychol Hum Percept Perform* 25:1595–1608
- Tipper SP, Howard LA, Jackson SR (1997) Selective reaching to grasp: evidence for distractor interference effects. *Vis Cogn* 4:1–38
- Tipper SP, Howard LA, Houghton G (2000) Behavioral consequences of selection from population codes. In: Monsell S, Driver J (eds) *Attention and performance*, vol 18. MIT Press, Cambridge, pp 223–245
- Van der Stigchel S (2010) The search for oculomotor inhibition: interactions with working memory. *Exp Psychol* 57:429–435
- Van der Stigchel S, Nijboer TCW, Bergsma DP, Abegg M, Barton JJS (2010) Anomalous global effects induced by ‘blind’ distractors in visual hemifield defects. *Brain Cogn* 74:66–73
- Van Opstal AJ, Van Gisbergen JAM (1990) Role of monkey superior colliculus in saccade averaging. *Exp Brain Res* 79:143–149
- Walker R, Deubel H, Schneider WX, Findlay JM (1997) Effect of remote distractors on saccade programming: evidence for an extended fixation zone. *J Neurophysiol* 78:1108–1119