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Short Communication

Relation between saccade trajectories and spatial distractor locations

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Abstract

This study shows that the exact spatial location of a distractor can have a modulatory influence on saccade trajectories. Distractors close to the target evoke saccade trajectories that are directed towards the distractor, while distractors close to fixation result in saccades that are directed away from the distractor. This finding questions the idea that target positions are coarsely coded in the superior colliculus.

Theme: Motor systems and sensorimotor integration
Topic: Oculomotor system

Keywords: Eye movement; Saccade; Superior colliculus

Eye movement trajectories are rarely fully straight [20]. The trajectories of fast eye movements (saccades) in a visual field with a single target are typically idiosyncratic and do not show much within-subject variability [1]. Moreover, saccade trajectories are known to be influenced by various factors. For instance, trajectories deviate away from irrelevant non-targets (distractors) [3,6], whereas deviation towards is observed in two-step [4] and visual search paradigms [7].

Deviation *away* from a distractor is assumed to be caused by inhibition of the vector that represents the distractor to select the target [7,11,15]. This inhibitory process also affects the target vector, causing the resulting vector to be pointed away compared to the original target vector. This then results in a saccade that is initially directed away from the target location. An independent feedback mechanism takes care of the deviation back towards the target location [10]. Deviation *towards* a distractor is associated with the lack of inhibition. When inhibition is absent, the executed vector will point in the direction of the combined target and distractor vector [15].

Evidence suggests that the precise spatial location of a distractor does not have a modulatory effect on saccade deviations [8,11]. This is an important finding because it suggests that object locations are coarsely coded in the brain area that has a major influence in target selection and the exact saccade execution, the superior colliculus (SC) [12]. Here, we investigate the relation between saccade deviation and distractor location on the basis of two hypotheses:

– Distractors presented within 20° of the target are known to influence saccade amplitude in that these distractors sometimes elicit a 'global effect' (saccades land in the direction of the distractor location) [2]. We therefore assume that saccade trajectories will be initiated *towards* the distractor when presented close enough to the target location.
– Research on reaching movements has shown that distractors close to the fixation point elicit large inhibition and therefore result in movements that are initiated *away* from the distractor location [15]. Because evidence suggests that reaching and eye movement trajectories are subject to roughly the same phenomena [16], it might be the case that this same finding can be observed for saccade trajectories.

On the basis of these two assumptions, we compared saccade trajectories to a target in the presence of a distractor that was either positioned close to fixation or close to the target location. If the two hypotheses indeed are reflected in

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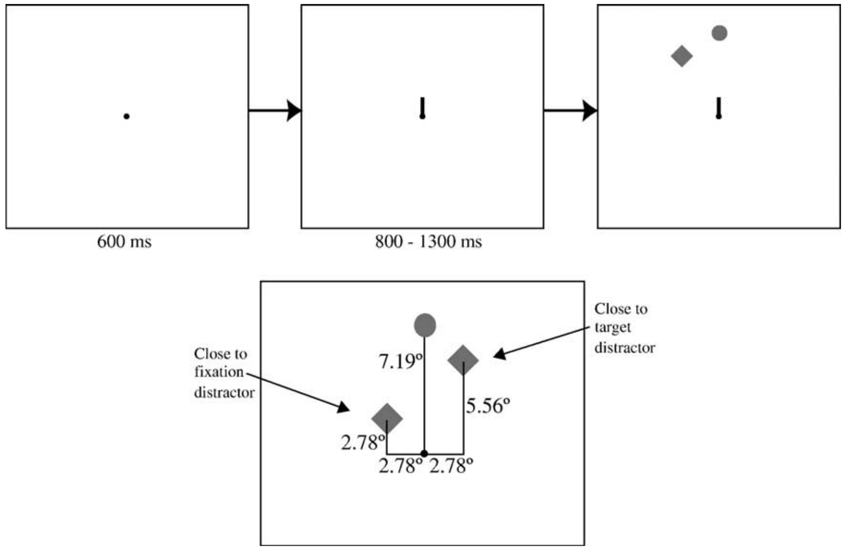

Fig. 1. Top: sequence of events on a trial in which the distractor was presented close to the target. Bottom: two examples of possible target locations (close to fixation and close to distractor) and the corresponding distances.

the data, this will provide evidence against the view that elements are coarsely coded in the SC and that the exact spatial location of a distractor has no influence on eye movement trajectories.

In the current experiment, the display started with a central fixation point. After 600 ms, a cue appeared pointing either upwards or downwards (see Fig. 1). Subjects were instructed to remain fixated at the central fixation point. A delay of 800–1300 ms then occurred followed by the onset of the target. The target was a light gray filled circle with a diameter of 0.54°. The location of the onset was related to the direction of the cue: i.e. if the line was pointing upwards, the target was presented 7.19° above fixation point. At the same time, a diamond shape distractor (0.81° × 0.81°) appeared at one of the four possible locations. The distractor was placed $x = \pm 2.78°$ and $y = \pm 2.78°$ (near fixation) or $y = \pm 5.56°$ (near target) from fixation point. The distance between the close to the fixation distractor and fixation was 3.93°, while the distance between the close to the target distractor and the target was 3.23°. The sequence of trials was randomly assigned.

Saccade trajectories to the target location were investigated by using two measures. We examined saccade deviation by calculating the mean angle of the actual saccade path relative to the angle of a straight line between the starting point of the saccade and the target location. The mean angle of the actual saccade path was calculated by averaging the angle of the straight line between fixation and all 2-ms sample points (e.g., [6,14]).

Furthermore, the initial saccade direction was examined by calculating the angle of the saccade 12 ms after its initiation[1] (see, for similar measures, [4,17]). Because the initial direction of the saccade and the feedback mechanism are assumed to be independent [10], the initial saccade direction will be independent of the saccade endpoint, providing a good indication of the direction of the vector on saccade initiation. Positive and negative deviations refer to angles towards and away of the distractor location, respectively.

The two measures were calculated for the two distractor locations and with respect to their latency. Saccade latency was defined as the interval between stimulus display onset and the initiation of a saccadic eye movement. To examine the relationship between saccade deviation and latency, we ordered the latencies in different bins. On the basis of their latency (fastest to slowest) and condition (close to fixation and close to target), for each participant, saccade trajectories were divided in two times five bins. By comparing the five bins, we could examine whether saccade trajectories change as a function of saccade latency for the two distractor locations. For each bin and each condition, we calculated the mean latency (see Table 1). There was no difference in mean latency per bin between the two conditions ($F(4,36) = 1.9$; $P > 0.10$).

An analysis of variance on saccade deviation with condition and bin showed a main effect of condition ($F(1,9) = 9.72$; $P < 0.02$). Distractors close to fixation point evoke a deviation away from the distractor (mean = −0.041 rad; standard error = 0.021 rad), while distractors close to the target location show a deviation towards the distractor (mean = 0.024 rad; standard error = 0.038 rad).

Table 1
Mean saccade latency for each bin for each condition

	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5
Close to fixation	181.3	217.2	237.0	261.2	320.8
Close to target	179.0	212.0	233.7	258.3	324.2

[1] It must be noted that McSorley et al. [8] adopted a different way to compute the saccade trajectory. Both measures are adequate ways to compute the initial saccade trajectory. However, it is possible that differences in findings are the result of using different measures.

Furthermore, a reliable interaction between condition and bin was revealed (see Fig. 2, $F(4,36) = 6.47$; $P < 0.001$). Planned comparisons shows that bin had an effect for the distractor close to target condition ($F(4,36) = 3.70$; $P < 0.02$) and that the saccades in the first bin deviated more towards the distractor than eye movements in the fifth bin ($t(5) = 5.40$; $P < 0.05$). For the close to fixation condition, no effect of bin was discovered ($F(4,36) = 1.98$; $P > 0.10$).

For the initial direction, the main results were identical. Besides a similar main effect of condition ($F(1,9) = 8.70$; $P < 0.02$), also an interaction between condition and bin was observed ($F(4,36) = 5.57$; $P < 0.002$). The factor bin had an effect on the distractor close to target condition ($F(4,36) = 3.42$; $P < 0.02$). In the condition in which distractors were presented close to fixation point, saccades were initiated away from the distractor (mean = −0.062 rad; standard error = 0.027 rad), whereas they were initiated towards the distractor when the distractor was presented close to the target (mean = 0.017 rad; standard error = 0.050 rad).

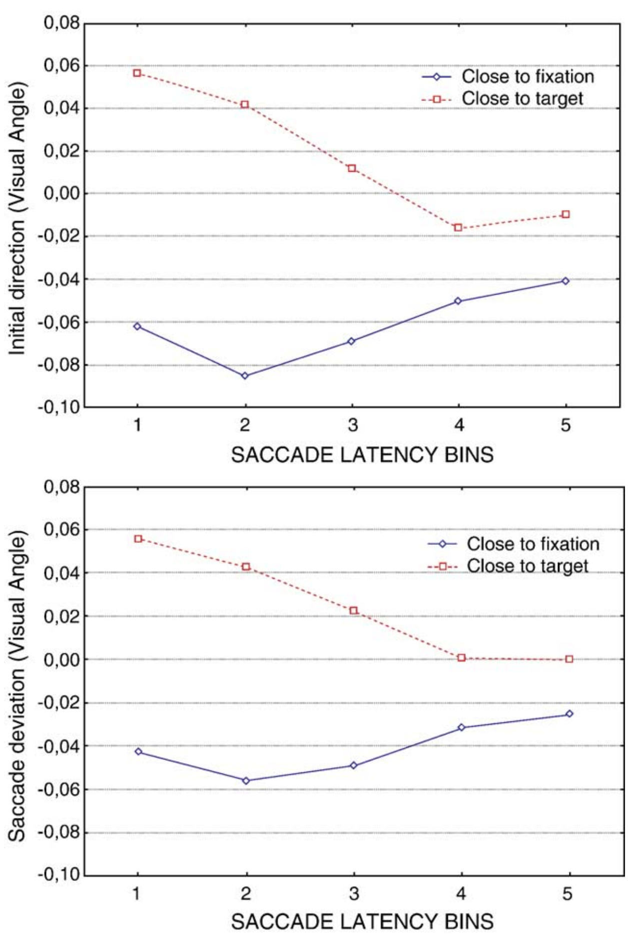

Fig. 2. The two measures of saccade trajectories represented for the five latency bins. Both graphs show that, when a distractor is presented close to the target, saccade trajectories are directed towards the distractor for fast eye movements. On the other hand, saccades to a target when a distractor is presented close to fixation are directed away from the distractor. The saccade latency bins correspond to those in Table 1.

Investigation of endpoint showed a reliable difference between the mean saccade endpoint and the target location for both conditions. The mean endpoint in the close to target condition landed in the direction of the distractor ($t(9) = 3.47$; $P < 0.01$; mean = 0.036 rad; standard error = 0.027 rad). Endpoints in the close to fixation condition landed in the quadrant contralateral to the distractor ($t(9) = 4.21$; $P < 0.01$; mean = −0.015 rad; standard error = 0.014 rad).

In contrast to previous studies [8,11], the current experiment shows that the exact spatial location of a distractor can have a distinct influence on saccade trajectories. Moreover, it shows that the distractor location can even evoke a difference in the direction of the saccade trajectory to a target location. If a distractor is presented close to fixation, saccade trajectories are directed away from the distractor, while a distractor close to the target location results in saccades that are directed towards the distractor. This difference is further reflected in endpoint characteristics in that distractors located close to the fixation cause saccades to end contralateral to the distractor location, while distractors close to the target location evoke the well-known global effect. In line with previous results [9,13], our results confirm that the number of saccades that are directed towards the distractor is higher for fast saccades. This effect was only observed in the condition in which the distractor was positioned close to the target location (see [9]).

The difference between the influence of the different distractor locations on saccade trajectories can be explained in terms of the vector theory [15]. In line with the findings for reaching behavior, distractors presented close to fixation are highly salient for the oculomotor system and therefore need to be inhibited to select the correct saccade location. Inhibition is also necessary for distractors positioned close the target location, but, because target and distractor are positioned so close together, the peaks of the two elements will merge. Because fast eye movements are mainly executed on the basis of bottom–up (exogenous) information [19], these movements will be initiated in the direction of the merged peak.

This account might also explain the difference between the present study and the McSorley et al. study [8]. In this study, the target element was less salient since it was not presented with abrupt onset. In our experiment, both target and distractor were presented with abrupt onset, generating two peaks of activation in the saccade map (e.g., superior colliculus). In order for peaks to merge, two peaks of activity are necessary [5,18]. This might explain why in the McSorley et al.'s experimental set-up saccades were not directed towards the distractor location when placed close to the target.

In summary, we found in contrast with previous research that object locations are not coarsely coded in the superior colliculus and that the exact spatial location can be reflected in saccade trajectories.

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