Eye cannot see it: The interference of subliminal distractors on saccade metrics

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Abstract

The present study investigated whether subliminal (unconsciously perceived) visual information influences eye movement metrics, like saccade trajectories and endpoints. Participants made eye movements upwards and downwards while a subliminal distractor was presented in the periphery. Results showed that the subliminal distractor interfered with the execution of an eye movement, although the effects were smaller compared to a control experiment in which the distractor was presented supraliminal.Because saccade metrics are mediated by low level brain areas, this indicates that subliminal visual information evokes competition at a very low level in the oculomotor system.

Introduction

Previous research has revealed that visual stimuli can affect visual attention without reaching awareness (e.g., Ansorge & Neumann, 2005; Ivanoff & Klein, 2003; Lambert, Naikar, McLachlan, & Aitken, 1999; McCormick, 1997; Mulckhuyse, Talsma, & Theeuwes, 2007; Woodman & Luck, 2003). For example, spatial cueing studies have found that a peripheral cue captured attention even though participants are unaware of this cue (McCormick, 1997; Mulckhuyse et al., 2007). In a traditional cueing study, a peripheral onset cue that is not informative of the upcoming target location is flashed briefly either to the right or the left of fixation point. A subsequent response to a target that appears at the cued location is faster and more accurate than to a target at the uncued location (Posner, 1980; Posner & Cohen, 1984). The same effect was found with a peripheral cue that did not reach awareness, indicating that that the subliminal cue captured attention (McCormick, 1997; Mulckhuyse et al., 2007).

Patients with visual field defects provide additional evidence for the effects of subliminal information on basic behavior. Due to a lesion of the retinogeniculostriate pathway or the striate cortex, these patients are unaware of visual stimuli in their blind visual field, but in some patients certain visual information is still processed, a phenomenon called ‘blindsight’ (Weiskrantz, 1986). For example, in a study by Kentridge, Heywood, and Weiskrantz (1999) a patient with blindsight responded faster to targets that appeared at the cued than at the uncued location, although he was unaware of both cue and target. This same patient was scanned in an fMRI study by Sahraie and colleagues (1997) in which they found that subcortical structures were activated in trials in which the patient reported no awareness of a visual event, although his discrimination performance of this visual event was above chance.

Recent evidence from patients with visual field defects demonstrated that visual information that is blind to the observer can still influence eye movement metrics, like saccade trajectories (Van der Stigchel, van Zoest, Theeuwes, & Barton, 2008). Patients were asked to make a vertical saccade to a visible target while a distractor appeared in their blind field. Results of two out of five patients showed that saccade trajectories deviated away from the distractor presented in the blind visual field. The goal of the present study was to investigate whether subliminal information can also influence basic oculomotor behavior in normal vision.

Saccade trajectory deviations are considered to reflect the competition between multiple saccade programs in the oculomotor system (for a review see, Van der Stigchel, Meeter, & Theeuwes, 2006). For instance, when participants have to search for a target presented in a search array, saccade trajectories to the target deviate towards the most salient distractor (Godijn & Theeuwes, 2002; McPeek, Skavenski, & Nakayama, 2000; Walker, McSorley, & Haggard, 2006). Besides deviations towards irrelevant distractors, deviations away are also frequently observed (Doyle & Walker, 2001; Van der Stigchel & Theeuwes, 2005, 2008). Deviations in saccade trajectories are generally explained in terms of the population coding theory (Tipper, Howard, & Jackson, 1997; Tipper, Howard, & Paul, 2001), which claims that both target and distractor are coded by active populations of neurons that represent a movement vector. When multiple vectors are active due to the presence of a distractor, the distractor vector has to be inhibited to resolve the competition. If not, the saccade will be initiated in the direction of the average vector, resulting in deviations towards a distractor. The inhibitory process shifts the final vector further away from the original target vector and thereby causing deviation away.

In the present study, participants had to make a vertical eye movement to a saccadic target that was either presented above or below fixation while in some trials a subliminal distractor was presented. In order to ensure that the distractor was presented at a subliminal level, we used the same method as Mulckhuyse et al. (2007). One of four circles in each trial was presented 17 ms earlier than the other three circles. Because the other three circles followed immediately after onset of the first circle ('distractor'), participants are unaware of this earlier onset. The circles were presented in a mirror symmetric position: two in the same field as the saccadic target and two in the opposite field of the target. Previous research has shown that a saccade trajectory is straightened when symmetric bilateral distractors are presented relative to when a single distractor is presented either in the same hemifield as the saccadic target or the opposite hemifield of the saccadic target (McSorley, Haggard, & Walker, 2004). To ensure that participants were unaware of the subliminal distractor they were not informed about its presence. Assessment of awareness of the distractor was performed in a separate task after participants performed the saccade task.

Note that the subliminal distractor was completely irrelevant and was not part of the attentional set of the participant: it did not resemble the target, it did not provide information about the appropriate response, it appeared at a location at which the saccadic target never appeared and participants did not have to report its presence in the session in which eye movements were recorded. We expected that the subliminal distractor would affect saccade metrics when it was present relative to when it was absent.

Experiment 1

Method

Participants

Seventeen paid volunteers (aged 18–25) participated in the experiment. All participants had normal or corrected to normal vision.

Apparatus

A Pentium IV computer with a processor speed of 2.3 GHz controlled the timing of the events. Displays were presented on an Iiyama 21 in. SVGA monitor with a resolution of 1024 x 768 pixels and a 60-Hz refresh rate. A second computer controlled the registration of eye movement's data on-line. Eye movements were registered by means of a video-based eye tracker (SR Research Ltd., Canada). The Eyelink 1000 Tower Mount system has a 1000 Hz temporal resolution and a <0.01° of gaze resolution (noise limited) and a gaze position accuracy of <0.5°. Data from the left eye was monitored and analyzed. The distance between monitor and chin rest was 75 cm.

Design

All stimuli were presented on a gray background (x = 0.284, y = 0.320, 6 cd/m2). The target display consisted of a light gray open diamond (x = 0.286, y = 0.318, 11 cd/m2) of 1.8° in diameter on both sides ('saccadic target'), and four filled circles each 1.4° in diameter of the same colour and luminance as the diamond. The circles were spaced in an imaginary square around the fixation point with a distance of 7.6° from fixation point to the centre of each circle. The distance between fixation point and the saccadic target was 9.1°.

Each trial began with a black plus sign. After 1400 ms and an additional random jitter between 0 and 400 ms, the fixation point disappeared and the saccadic target and circles were presented. In the distractor present trials, one of the circles was presented 17 ms before the offset of the fixation point and the saccade target and other circles were presented. We will refer to this item as the distractor. Fig. 1a shows the sequence of a trial in which the distractor was presented in the opposite field of the saccadic target.

The experiment consisted of two sessions. One session with eye movements (eye movement task) and one session without eye movements (distractor report task). The first session (eye movement task) consisted of 320 trials: 64 trials without a distractor (neutral condition), 128 trials in which a distractor was presented in the same field as the saccadic target (same field condition) and 128 trials in which a distractor was presented in the field that was opposite to the saccadic target (opposite field condition). Participants started the experiment with a practice block of 25 trials. The trials were randomly distributed throughout a block. The saccadic target appeared equally often above or below fixation point. The second session (distractor report task) consisted of 64 trials in which the distractor was always presented and the saccadic target was absent.

Procedure

Eye movement task.

Before the experiment started, the Eyelink 1000 system was calibrated. Participants had to fixate nine calibration targets that were presented randomly in a 3 x 3 grid across the monitor. On each trial in the experiment, participants were instructed to fixate the fixation point and to press the space bar in order to recalibrate the position of the eyes. The fixation point then changed into a plus sign as an indication that the positions of the eyes were recalibrated.

Participants were told to make a saccade to the saccadic target. To avoid anticipation saccades a warning beep was presented when participants responded too fast, before 80 ms. The warning beep was also presented when participants responded too slow, after 600 ms.

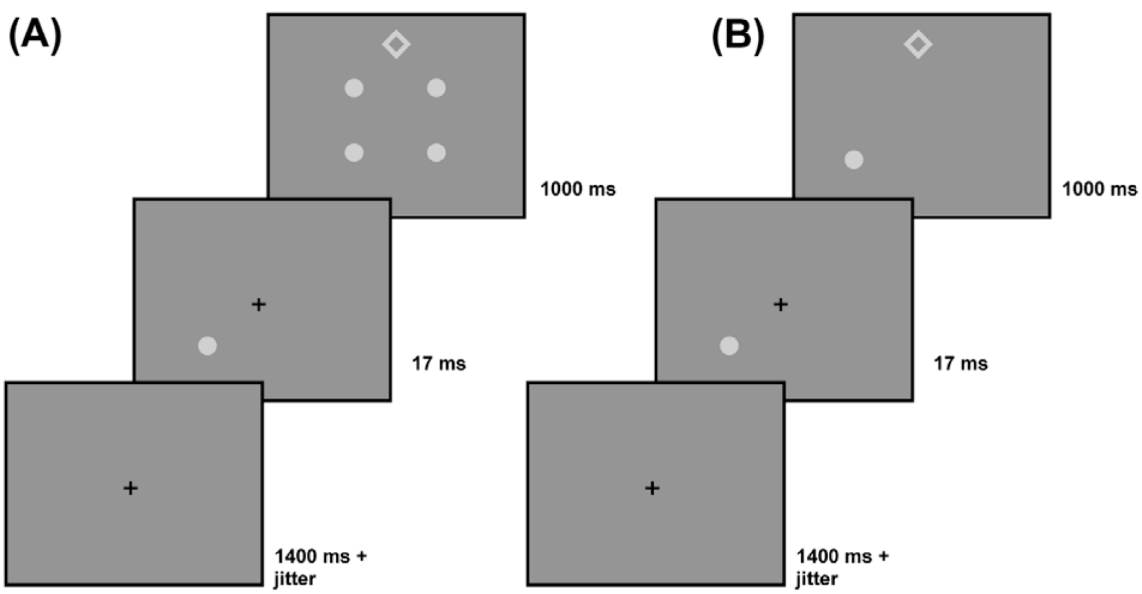

Fig. 1. (a) Experiment 1: from bottom to top, the sequence of a trial in which the distractor was presented in the visual field opposite to the saccadic target; (b) the same type of trial, but now for Experiment 2.

Distractor report task

Participants were asked to report the location of the distractor. Participants responded by pressing the 7, 9, 1 or 3 on the numeric keyboard. The locations on the keyboard corresponded with the locations on the monitor. Each trial started with the same procedure as in the first session with respect to the recalibration of the eye tracker. The likelihood that the distractor appeared at one of the four possible locations was similar in the both tasks.

Data analysis

A saccade was defined as a correct saccade if the starting position was within 1° of horizontal distance and within 2° of vertical distance from the centre fixation point. Furthermore, the end position of the saccade had to have an angular deviation of less than 22.5° from the centre of the saccadic target. Saccade latency was defined as the interval between target onset and the initiation of a saccade. Saccade latencies shorter than 80 ms and higher than 600 ms were excluded from analyses. Latencies shorter or higher than 2.5 standard deviations away from the mean latency were also excluded. Moreover, too small saccades (<3°) were excluded from analyses.

Saccade trajectories to the target location were examined by calculating the mean angle of the actual saccade path relative to the mean angle of a straight line between the starting point of the saccade and the saccadic target. The angle of the actual saccade was calculated for each 2-ms sample point by examining the angle of the straight line between the starting point of the saccade and the current sample point. Angles were averaged across the whole saccade and subtracted from the angle of the straight line between fixation and the target location (for a more detailed overview of saccade trajectory computation, see, Van der Stigchel et al., 2006). To compute the influence of the distractor on saccade trajectories, for each saccade we compared trials with a distractor to the averaged mean-path-angles of all trials without a distractor (i.e. the neutral condition) to determine whether the saccade in the presence of a distractor deviated towards or away from the location of the distractor. Deviations were signed so that a positive value indicated deviation towards the distractor and a negative value deviation away.

Results

Distractor report task

A one-tailed binomial test for each participant revealed that five of the 17 participants scored significantly above chance level (25%) on the distractor detection task suggesting that they were aware of the presence of the distractor. Because our study was about subliminal cueing these subjects were excluded from further analyses. There was no difference between the detection of distractors presented near or far from the target ($t(11) = 0.17$; $p > 0.80$). There was also no difference between detection of distractors at the four locations ($F(3, 33) = 0.74$, $p > .50$). For the 12 participants included in further analyses, Fig. 2 shows individual performance per position.

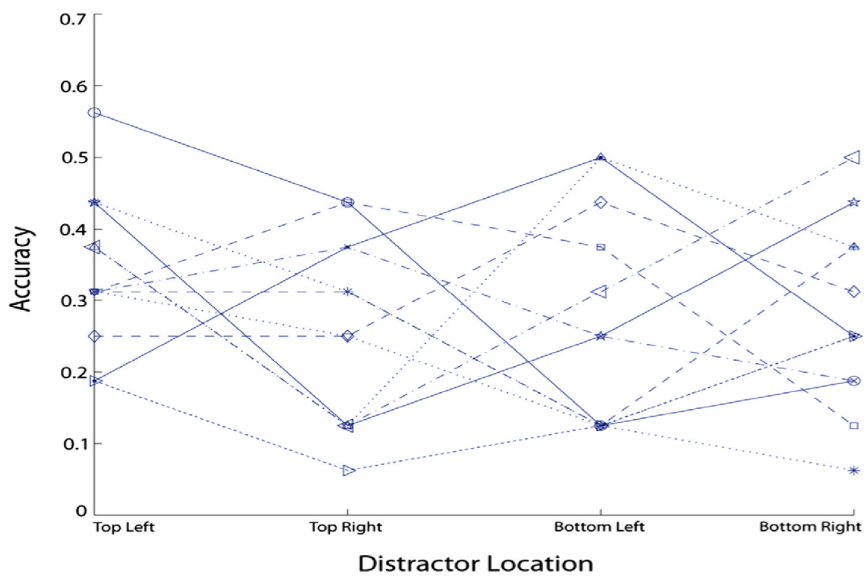

Fig. 2. Individual performance per position for the twelve participants included in further analyses. Although performance for some participants seems to be higher than chance level for some locations, this is always accompanied by a location at which performance is lower than chance level. This likely reflects response biases for answering a certain location.

Eye movement session

Based on the criteria described above, 12.3% of all trials were excluded from analyses.

A repeated measures ANOVA on saccade latency with Distractor Condition (no distractor, distractor in same field, distractor in opposite field) as a factor showed that there was no main effect of Distractor Condition ($F(2, 22) = 2.24$, $p > .10$). The mean saccade latency was 217 ms (SEM = 5.77 ms).

Mean saccade deviation in the same field condition was 0.0859_ (SEM = 0.0943_) and did not differ from zero (t(11) = .91; p > .30). Mean saccade deviation in the opposite field condition was _0.1776_ (SEM = 0.0612_) and differed significantly from zero (t(11) = 2.86, p < .02). In addition, there was a significant difference between the same and the opposite condition (t(11) = 3.26, p < .01). See Fig. 3 for an example of mean trajectories for one participant.

An effect of saccade deviation was only observed when the distractor was presented in the opposite field of the saccadic target. There was no effect of the distractor when it was presented in the same field as the saccade target. To investigate whether an effect of the distractor might be observed on the saccade endpoint, we investigated whether the endpoint of the saccade was shifted when the distractor was present compared to when the distractor was absent. An analysis of endpoint deviation showed that the endpoint was shifted towards the distractor when it was presented in the same field as the saccadic target (mean endpoint deviation differed significantly from zero; mean = 0.2693_; SEM = 0.0711_; t(11) = 3.84; p < .01). This effect was absent when the distractor was presented in the opposite field of the saccade target (mean = _0.0011_; SEM = 0.0645_; t(11) = 0.13; p > .90). In addition, there was a significant difference between the same and the opposite condition (t(11) = 3.55, p < .01).

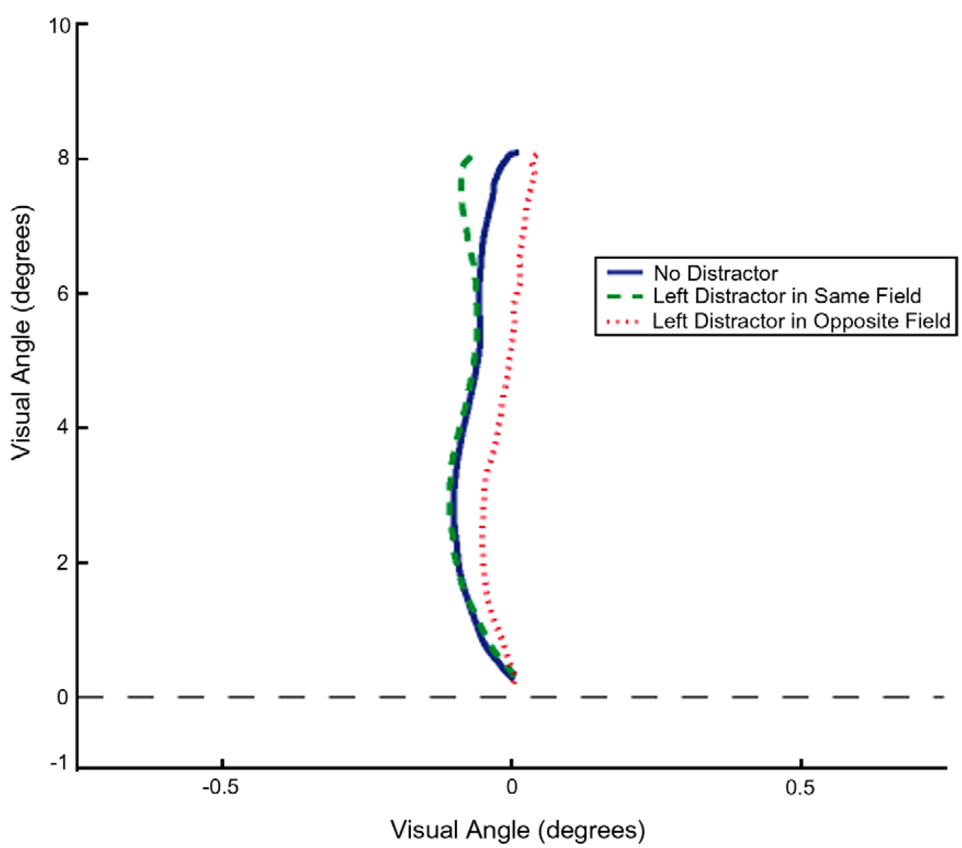

Fig. 3. An example of mean trajectories for one participant. Displayed are the mean trajectories for upward saccades when the distractor was either absent, presented on the left side in the same visual field as the saccadic target or presented on the left side in the visual field opposite to the saccadic target. It can be seen that the endpoint of the saccade is shifted in the direction of the distractor when the distractor is presented in the same visual field as the saccadic target. However, when the distractor is presented in the visual field opposite to the saccadic target, the trajectory deviates away compared to the condition in which no distractor is presented.

Discussion

Experiment 1 investigated whether a subliminal distractor influences saccade trajectories. Results showed that when participants made saccades upwards and downwards, a task irrelevant distractor presented in the opposite hemifield influenced saccade trajectories in that the eye movement deviated away from the distractor. However, when the subliminal distractor was presented in the same field as the target, the effect on saccade deviation was absent. In this condition, a small but significant effect on saccade endpoint was observed. The endpoint was shifted towards the distractor. To compare these results with supraliminal behavior, a control experiment was conducted in which the distractor was visible to the participant.

Experiment 2

Method

Participants

Twelve paid volunteers (aged 19–27) participated in the experiment.

Apparatus, design, procedure, and data analysis

Experiment 2 was similar to Experiment 1 except that no masks were presented. The distractor was present 17 ms before the target but was not removed during the trial. It was therefore visible to the participant from the moment it was presented until the end of the trial. Fig. 1b shows the sequence of a trial in which the distractor was presented in the opposite field of the saccadic target.

Results and discussion

Distractor report task

All participants were aware of the presence of the distractor.

Eye movement session

Based on the criteria described, 19.9% of all trials were excluded from analyses.

A repeated measures ANOVA on saccade latency with Distractor Condition (no distractor, distractor in same field, distractor in opposite field) as a factor showed that there was a main effect of Distractor Condition (F(2, 22) = 58.12, p < .0001). Post hoc t-tests showed that the latency in the no-Distractor Condition was significant lower (mean = 180 ms; SEM = 5.20 ms) than when the distractor was presented in the same field (mean = 188 ms; SEM = 5.20 ms; t(11) = 5.29; p < 0.001) and when the distractor was presented in the opposite field (mean = 203 ms; SEM = 6.06 ms; t(11) = 8.05; p < 0.0001). Furthermore, saccade latencies were lower when the distractor was presented in the same field compared to when it was presented in the opposite field (t(11) = 7.96; p < 0.0001). This is different from the results of Experiment 1 in which no significant effect on saccade latency was observed.

Mean saccade deviation in the same field condition was 1.4496_ (SEM = 0.5954_) which differed from zero (t(11) = 2.44; p < .05). Mean saccade deviation in the opposite field condition was _0.4240_ (SEM = 0.1323_) and differed significantly from zero (t(11) = 3.15, p < .01). In addition, there was a significant difference between the same and the opposite condition (t(11) = 3.25, p < .01). To sum up, saccades trajectories deviated towards the distractor when it was presented in the same field as the target, whereas they deviated away from the distractor when it was presented in the opposite field.

An analysis of endpoint deviation showed that the endpoint was shifted towards the distractor when it was presented in the same field as the saccadic target (mean 0.8824_; SEM = 0.3473_; t(11) = 2.59; p < .03). The endpoint was shifted away from the distractor when it was presented in the opposite field of the saccade target (mean = _0.4297_; SEM = 0.0992_; t(11) = 4.32; p < .01). In addition, there was a significant difference between the same and the opposite condition (t(11) = 3.73, p < .01).

Experiment 1 versus Experiment 2

To test whether there is a difference in the magnitude of the distractor interference between the two experiments, we run a mixed ANOVA with Experiment as a between-subjects factor. For saccade deviation, there was a significant effect of Experiment for the condition in which the distractor was presented in the same field as the target ($F(1, 22) = 5.12$, $p < .05$), in that deviations were stronger in Experiment 2. This effect was absent for distractors in the opposite field ($F(1, 22) = 2.84$, $p = .11$). For saccade endpoint, there was a trend for an effect of Experiment when the distractor was presented in the same field as the target ($F(1, 22) = 3.08$, $p = .09$). There was an effect of Experiment when the distractor was presented in the opposite field ($F(1, 22) = 13.19$, $p < 0.01$), in that the shift of saccade endpoint was stronger in Experiment 2. Overall, saccade latencies were shorter in Experiment 2 compared to Experiment 1 ($F(1, 22) = 10.74$, $p < 0.01$).

General discussion

The goal of the present study was to investigate whether subliminal information influences basic oculomotor behavior. To this end, we studied the effect of a distractor circle which was presented 17 ms earlier than three other non-target circles. When asked which circle appeared earlier, participants were unaware of this earlier onset (‘distractor’). Even though the earlier

presented distractor circle was not consciously perceived, earlier research using the same paradigm revealed that such an earlier distractor circle still can capture attention reflexively (Mulckhuyse et al., 2007). To understand whether this visual subliminal information affects basic oculomotor behavior as well, we tested whether this distractor circle would evoke interference on the execution of an eye movement. Distractors were presented both in the same or the opposite field as the target. Results showed that the subliminal distractor had a small, but significant, effect on the saccade metrics. When the distractor was presented in the visual field opposite to the saccadic target, saccade trajectories deviated away from the distractor. However, when the distractor was presented in the same visual field as the target, the saccade endpoint was influenced but no effect on the saccade trajectory was observed. In this condition, the saccade endpoint was shifted towards the distractor.

In Experiment 2, we determined how these effects relate to the supraliminal behavior. By only presenting the distractor and the target, we determined whether the results of the subliminal experiment were specific to unconscious behavior. Results showed that the effects were similar as those observed in Experiment 1, even though they were stronger. When a supraliminal distractor was presented in the same field as the target, not only the saccade endpoint was shifted, but also the trajectory deviated towards the distractor. The stronger effects might partly have been caused by the shorter saccade latencies in Experiment 2, because saccade deviations towards a distractor have been found to be stronger for shorter latencies (McSorley, Haggard, & Walker, 2006).

The finding of a global effect for same field distractor in our experiment was somewhat surprising, because it is known that this effect typically occur when the distractor is presented in a limited zone (±20°) around the target location (Walker, Deubel, Schneider, & Findlay, 1997). In our experiment, the distractor was presented outside this zone (at 45_). The finding that this effect was also observed for a supraliminal distractor excludes the possibility that this effect is specific for supraliminal information. There are various possible explanations why a global effect was observed in the present experiment. For instance, saccades were fast, increasing the possibility of a global effect (e.g., Van der Stigchel & Theeuwes, 2005). Furthermore, both elements were presented with abrupt onset, which increases the likelihood of a global effect (Van der Stigchel, Meeter, & Theeuwes, 2007a).

One could argue that the distractor was not subliminal and the visibility measure was not significant in the distractor report task because of the lower number of trials than in the eye movement task (limiting the statistical power compared to the eye movement task). This would implicate that the distractor was not subliminal in the eye movement task. Even though possible, we consider this highly unlikely because the status of the distractor was different between the two tasks. In the eye movement task, the distractor did not have to be reported, but an eye movement had to be made to the target which was clearly visible. Therefore, the distractor was task-irrelevant and its localization was not part of the task set of the participant. However, in the distractor report task, participants were explicitly asked to report the location of the distractor. This is a very stringent test because in the distractor report task, participants actively tried to determine the location of the distractor. Note that we only included those participants in the eye movement task who truly did not see the distractor in the distractor report task even when they explicitly tried to do so. We therefore feel comfortable that these participants were unaware of the distractor in the eye movement task.

The present results are reminiscent of a study investigating whether subliminal colour primes influence trajectories of pointing movements to a target (Schmidt, 2002). Results showed that pointing trajectories were affected by priming, because movements were initiated towards the prime whose colour was inconsistent with the colour of the target. Note that the masked stimulus was presented at the possible target locations, while in the present study the distractor was presented at a task-irrelevant location. Although the finding that in our study eye movement trajectories deviated away from the subliminal distractor might seem inconsistent with the deviation towards observed in the study of Schmidt (2002), it has to be noted that differences in the direction of the deviation between hand and eye movements are commonly observed (Sheliga, Craighero, Riggio, & Rizzolatti, 1997; Van derStigchel, Meeter, & Theeuwes, 2007b). This is in line with the idea that inhibitory effects underlying deviations away are not observed in similar situations for hand and eye movements (Van der Stigchel et al., 2007b).

One possible neural interpretation why a visual stimulus that is not consciously perceived may still be able to affect oculomotor processes involves the superior colliculus (SC), a motor area in the midbrain. Among other brain structures, the SC is very much involved in attentional and oculomotor processes (see for reviews, Munoz, 2002; Shipp, 2004). Interestingly, saccade deviations are believed to reflect competition between saccade goals in the SC (McPeek, Han, & Keller, 2003). Because the present study shows that subliminal distractors influence saccade dynamics, this indicates that subliminal information evokes competition at a low level
in the oculomotor system.

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