

Oculomotor capture by surprising onsets

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The present study examined the effect of surprising onsets on oculomotor behaviour. Participants were required to execute a saccadic eye movement to a colour singleton target. After a series of trials an unexpected onset distractor was abruptly presented on the surprise trial. The presentation of the onset was repeated on subsequent trials. The results showed that the onset captured the eyes for 28% of the participants on the surprise trial, but this percentage decreased after repeated exposure to the onset. Furthermore, saccade latencies to the target were increased when a surprising onset was presented. After repeated exposure to the onset, latencies to the target decreased to the preonset level. The results suggest that when the onset is not part of participants' task set it has a strong effect on oculomotor behaviour. Once the task set has been updated and the onset no longer comes as a surprise its effect on oculomotor behaviour is dramatically reduced.

When human observers explore the world around them they scan their visual environment by generating saccadic eye movements to different regions of the visual environment. In order to interact adaptively with the visual environment observers typically execute saccades to regions of the visual environment that are relevant for their goals, while ignoring those that are irrelevant. However, previous research has shown that under certain conditions observers often execute saccades to salient properties of the visual environment despite their irrelevance for the observer's goals.

For example, Theeuwes et al. (Theeuwes, Kramer, Hahn, & Irwin 1998; Theeuwes, Kramer, Hahn, Irwin, & Zelinsky, 1999) required participants to search for a uniquely coloured grey circle (colour singleton target), presented together with red distractor circles, and to determine whether it contained a "c" or a "reversed-c". On half the trials there was an abrupt onset of an additional red circle. The results showed that on the majority of trials participants directly moved their eyes towards the colour singleton target. However, on about a third of the trials participants first moved their eyes

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towards the onset distractor, despite the fact that the onset was task-irrelevant. According to Theeuwes et al., the onset captured attention and resulted in the programming of a stimulus-driven saccade towards the onset. Because of the presumed stimulus-driven nature of these saccades to the onset, they have been referred to as oculomotor capture. Subsequent research has replicated the major findings of Theeuwes et al., although the degree to which onsets capture the eyes varies widely between different versions of the oculomotor capture task (e.g., Godijn & Theeuwes, 2002b; Irwin, Colcombe, Kramer, & Hahn, 2000) and some studies have found a much lower frequency of oculomotor capture by onsets under certain conditions (e.g., Godijn & Kramer, 2006; Ludwig & Gilchrist, 2002). Although a comparison of these studies is complicated due to the many differences in the stimulus displays, one factor that likely contributes to the percentage of oculomotor capture is the saccade latency distribution. Specifically, previous studies have found that saccades to the onset have shorter latencies than saccades to the target (e.g., Godijn & Theeuwes, 2002b; Theeuwes et al., 1998). Indeed, in Godijn and Kramer (2006) oculomotor capture was negligible and saccade latencies to the colour singleton target were around 300 ms, while in earlier studies (Godijn & Theeuwes, 2002b; Theeuwes et al., 1998, 1999) there was about 30% oculomotor capture and mean saccade latencies to the target were around 220 ms.

In the oculomotor capture task the presentation of the onset is predictable for participants. In some studies the onset is presented on all trials (e.g., Godijn & Theeuwes, 2002a); in other studies the onset is presented on half the trials (e.g., Godijn & Theeuwes, 2002b; Theeuwes et al., 1998). In each of these studies, participants developed expectations concerning the onset of a new distractor. That is, participants knew that an onset would be presented (or could be presented) and they knew that it would not be the target. Furthermore, the onset typically provides the participant with temporal knowledge about the target. Specifically, in most studies on oculomotor capture (e.g., Godijn & Theeuwes, 2002b; Theeuwes et al., 1998) the onset is presented simultaneously with the colour singleton target. It has been suggested that features that signal the appearance of the task-relevant display may capture attention (e.g., Gibson & Kelsey, 1998). Therefore, in the oculomotor capture task participants may attend to the onset, because of the temporal information it gives concerning the target presentation.

The goal of the present study is to examine the effect of a surprising onset on oculomotor behaviour. To what extent does an onset capture the eyes and impair oculomotor search for a colour singleton target when its presentation is unexpected? Although the effect of surprising onsets on oculomotor behaviour has not yet been addressed, two previous studies have examined whether a surprising colour singleton captures covert attention. Gibson and

Jiang (1998) presented participants with displays containing eight white letters arranged in a circle. Participants' task was to determine which of two possible target letters was presented among the distractors. After 192 trials on which all letters were always white, the target on all subsequent trials was a red colour singleton letter. It was expected that if the colour singleton captured attention accuracy should have been higher on the surprise trial (the first trial on which the colour singleton target appeared) than on the preceding trials. The results indicated no significant difference in performance between the surprise trials and the preceding trials. However, accuracy was higher on the trials following the surprise trial, which indicated that participants were able to use their newly developed expectations concerning the colour singleton to their advantage. The finding that the colour singleton did not capture attention on the surprise trial was replicated in a second experiment in which the colour singleton was a distractor letter on the surprise trial and all subsequent trials; again no significant difference in accuracy was found between the surprise trial and preceding trials.

More recently, Horstmann (2002, 2006) showed that the effect of the surprise colour singleton depends on the stimulus-onset asynchrony (SOA) between the presentation of the colour singleton and the target letter. In Horstmann (2002) the target and distractor letters were presented on red or green squares. On the first 48 trials all squares were the same colour, but on the subsequent "surprise" trial the target letter was presented on a uniquely coloured square. The results showed that accuracy was higher on the surprise trial than on the preceding trials when the colour singleton square was presented at least 400 ms prior to the target letter. Horstmann (2006) argued that surprising colour singletons do capture attention, but that this is a relatively slow process compared to the capture of attention by expected stimuli.

The studies of Horstmann (2002, 2006) and Gibson and Jiang (1998) examined the effect of a surprising colour singleton on attentional capture. Little is yet known about the effect of a surprising onset. Although there is evidence that onsets attract attention more robustly than other features (e.g., Jonides & Yantis, 1988; Yantis & Jonides, 1984), it has also been shown that attentional capture by onsets depends on the allocation of attention prior to the onset presentation. Specifically, when attention is allocated to the target location prior to the presentation of the onset it no longer captures attention (e.g., Theeuwes, 1991; Yantis & Jonides, 1990). Interestingly, Neo and Chua (2006) have recently demonstrated that this effect is modulated by the frequency of onset presentation. In one experiment they replicated earlier findings that when an onset is presented on the majority (75%) of trials, attending to the target location prior to the onset presentation prevents attentional capture by the onset. However, in a subsequent experiment it was found that when the onset was presented infrequently (20% of trials) it

captured attention even when attention was directed to the target location prior to the onset presentation. These results suggest that the novelty of the onset plays a role in its ability to capture attention.

The goal of the present study is to examine the effect of surprise on oculomotor capture. Previous studies examining the effect of surprise have focused on attentional capture (Gibson & Jiang, 1998; Horstmann, 2002, 2006). However, it may be expected that under normal circumstances observers are likely to move their eyes to surprising events that capture their attention. In the present study we address the effect of surprise on oculomotor behaviour in a modified version of the oculomotor capture task. We have chosen this task, because it has been quite extensively studied (e.g., Godijn & Theeuwes, 2002a, 2002b; Irwin et al., 2000; Kramer, Gonzalez de Sather, & Cassavaugh, 2005; Kramer, Hahn, Irwin, & Theeuwes, 1999; Theeuwes et al., 1998, 1999), but always in conditions in which participants have developed expectations concerning the presentation of the onset distractor. In contrast to previous studies of oculomotor capture, in which the onset distractor is presented throughout the whole experiment on a proportion of trials, in the present study the onset distractor is only presented in the second half of trials. Thus, for the first half of the experiment participants are required to execute a saccade to a uniquely coloured target, but no onset distractor is presented. This allows participants to develop a task set related to the target and the non-onset distractors. Since the onset distractor is not presented in the first half of the experiment, the developed task set does not contain information concerning onset distractors. Then, in the second half of the experiment an onset is presented on every trial. Initially, the presentation of the onset is surprising since it is not part of the task set. If the novelty of the onset distractor modulates the degree to which it captures the eyes, it is expected that on the very first onset trial (the surprise onset trial) the onset will capture the eyes. After repeated exposure to the onset it becomes part of the task set. That is, participants become aware that an onset is presented and that it is task irrelevant. If this information is included in participants' task set their ability to ignore the onset should improve as a function of repeated exposure.

METHOD

Participants

After giving their informed consent, 50 students from the University of Illinois with normal or corrected-to-normal vision served as paid volunteers.

Stimuli, procedure, and design

Prior to each trial participants fixated a central dot and pressed the spacebar to start the trial. Then, six equidistant grey circles (1.2° in diameter; luminance 16.0 cd/m^2) were presented on an imaginary circle with a radius of 9.2° around a central fixation point (see Figure 1). After 600 ms all but one of the circles turned red (luminance 15.3 cd/m^2), leaving a uniquely coloured (singleton) grey circle. The task of participants was to execute a saccade toward the colour singleton. Each participant completed a total of 64 trials. On the 33rd trial (the surprise onset trial) and on all subsequent trials an abrupt onset was presented simultaneously with the colour change of the distractors on the imaginary circle. The colour singleton target was

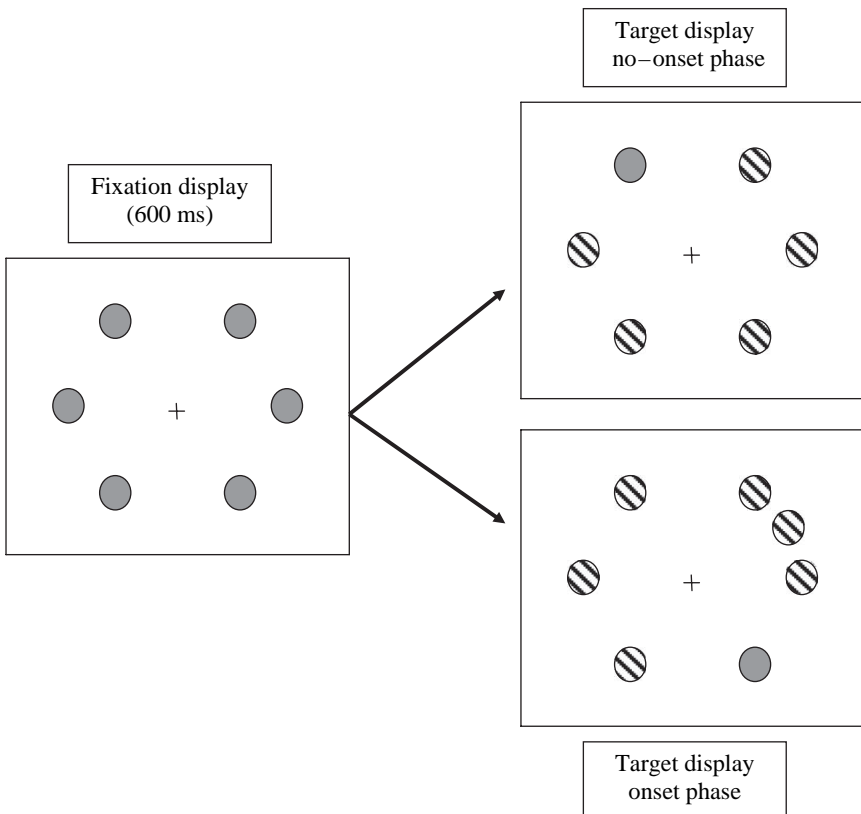


Figure 1. Examples of the display sequence. During the no-onset phase all but one of the circles turn red leaving a grey colour singleton target. This is followed by the onset phase in which there is an unexpected abrupt onset of a new red distractor circle simultaneously with the colour change of the distractors.

randomly presented at clock position 1, 5, 7, or 11 and the abrupt onset was randomly presented at clock position 2, 4, 8, or 10. A Pentium-based computer with a 21-inch colour monitor controlled the timing of events and generated stimuli. Eye movements were recorded by means of an Eyelink II tracker.

RESULTS

A total of 3.3% of the trials were discarded from further analyses, because saccade latency was either shorter than 80 ms (anticipations) or longer than 800 ms. None of the surprise onset trials (the 33rd trial) was discarded on this account.

The initial saccade was assigned to a particular object if the endpoint of the initial saccade had an angular deviation of less than 15° of arc (i.e., half the distance between the onset and its neighbouring objects) from the centre of the object on the imaginary circle around the central fixation point.

Oculomotor capture

In the following data presentation the percentages refer to percentages of trials per subject averaged across subjects. However, since there is only a single surprise trial per subject percentages related to the surprise trial refer to averages across subjects. In the no-onset phase (first half of experiment) the initial saccade was directed to the target on 83.7% of trials. In the onset phase (second half of experiment) the initial saccade was directed to the target on 69.6% of trials and to the onset on 10.0% of trials. On the surprise onset trial (the first trial with an onset) the onset captured the eyes of 28% of the subjects; that is, these subjects first moved their eyes to the onset. Figure 2 shows the percentage capture as a function of trial number. In order to examine the effect of repeated exposure to the onset we grouped the trials of each subject into bins of eight trials. A within-subjects analysis of variance (ANOVA) on the percentage capture revealed a significant effect of repeated exposure to the onset (bin), $F(3, 147) = 28.07$, $p < .001$. As can be seen in Table 1 (also see Figure 2) the percentage capture decreased as a function of repeated exposure to the onset. Planned comparisons revealed that there was more capture in bin 5 (the first eight trials of the onset phase) than in bin 6, $t(49) = 4.68$, $p < .001$, and more capture in bin 6 than in bin 7, $t(49) = 2.49$, $p < .02$, but there was no difference between bins 7 and 8, $t(49) < 1$. Furthermore, the percentage of capture was greater on the surprise onset trial than on subsequent trials, $t(49) = 3.03$, $p < .05$.

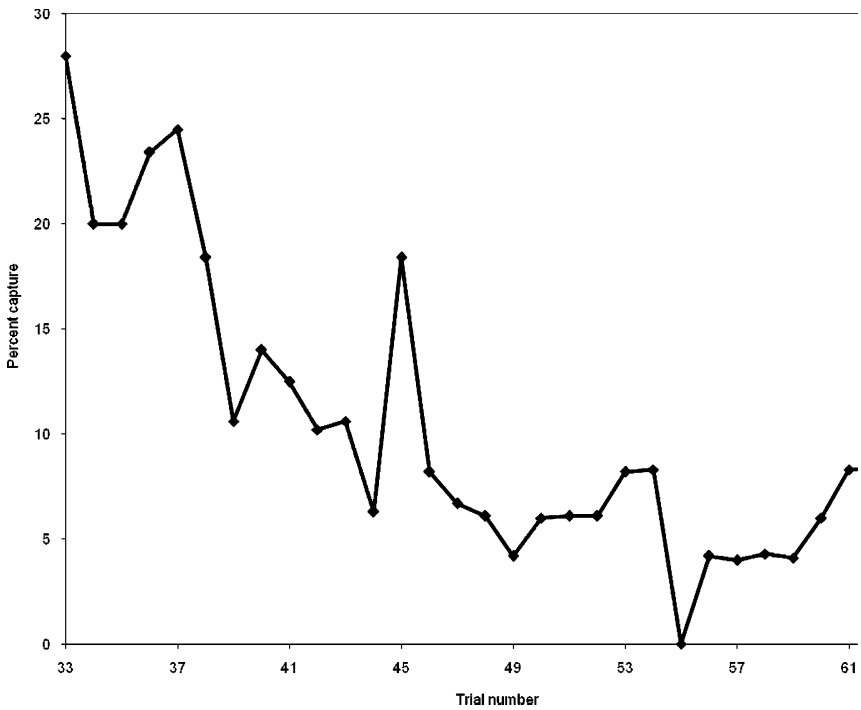


Figure 2. Percentage capture as a function of trial number (the first 32 trials are not shown because no onset was presented).

Saccade latencies

In the onset phase initial saccade latencies to the onset were shorter (mean 253 ms) than to the target (mean 332 ms), $t(39) = 7.12, p < .001$ (10 subjects were excluded in this analysis because they did not make any saccades to the

TABLE 1
Percentage capture and mean saccade latencies to the target across the time course of the experiment (the 64 trials are split into 8 bins of 8 successive trials)

<i>Bin</i>	<i>Percentage capture</i>	<i>Mean latency of saccades to the target</i>
1	X	375 ms
2	X	324 ms
3	X	315 ms
4	X	313 ms
5	20.0%	348 ms
6	9.9%	333 ms
7	5.5%	321 ms
8	5.0%	313 ms

onset). There was a significant effect of bin on saccade latencies to the target, $F(7, 343) = 11.52, p < .001$. Table 1 shows that saccade latencies to the target decrease as a function of bin until the onset phase, reflecting a practice effect. Then, at the beginning of the onset phase there is an increase in saccade latencies to the target. Planned comparisons revealed that saccade latencies to the target were significantly longer in bin 5 (the first trials in the onset phase) than in bin 4 (the last trials in the no-onset phase), $t(49) = 3.83, p < .001$, and they were longer in bin 6 than in bin 4, $t(49) = 2.08, p < .05$. There was no significant difference in mean saccade latency between bin 4 and bins 7 and 8, $t_s < 1$. Planned comparisons were also conducted between the surprise onset trial and subsequent trials. For subjects who executed a saccade to the target on the surprise onset trial (29 subjects), saccade latency was longer on the surprise onset trial (mean 372 ms) than on subsequent trials on which the eyes moved to the target (mean 328 ms), $t(28) = 2.06, p < .05$. For subjects who executed a saccade to the onset on the surprise onset trial (14 subjects; one subject was discarded from this analysis because there were no subsequent oculomotor capture trials), there was no significant difference in saccade latency between the surprise onset trial (mean 236 ms) and subsequent oculomotor capture trials (mean 262 ms), $t(12) = 1.44, p > .15$.

DISCUSSION

The results of the present study showed that surprising onsets have a strong effect on oculomotor behaviour. When participants were not expecting an onset to be presented, the onset captured the eyes of 28% of the subjects. As the novelty of the onset decreased after repeated exposure, the percentage of oculomotor capture decreased. Furthermore, the surprising onset also affected the latencies of eye movements to the target. During the first onset trials saccade latencies to the target had increased relative to the last trials of the no-onset phase by an average of 35 ms. After repeated exposure to the onset the latency increase was reduced and in the third quarter of the onset phase (after 16 onset trials) there was no significant difference in saccade latencies to the target relative to the last trials of the no-onset phase. These results suggest that it took participants on average about 15 to 20 trials to adjust to the presentation of the task-irrelevant onset.

A number of previous studies (e.g., Godijn & Theeuwes, 2002b; Theeuwes et al., 1998, 1999) have demonstrated oculomotor capture to some extent similar to the oculomotor capture on our surprise trials. These studies found oculomotor capture on about 30% of the trials despite the fact that the onset was not unexpected. However, a major difference between the present study and these previous studies (e.g., Godijn & Theeuwes, 2002a, 2002b; Theeuwes

et al., 1998, 1999) is that saccade latencies in the previous studies were typically much shorter (just over 200 ms on average) than in the present study (over 300 ms on average). Indeed, saccade latencies to the target were quite similar to Godijn and Kramer (2006) Godijn and Kramer (2006a) study in which the percentage of oculomotor capture was negligible. Furthermore, in the present study oculomotor capture was reduced to about 5% when the presentation of the onset was no longer surprising. The reduction from 28% to 5% indicates a substantial effect of surprise on oculomotor capture.

The results of the present study suggest that participants are unable to ignore the onset when its presentation is surprising and no task set has been developed concerning the onset. Not only does the onset capture the eyes of some of the participants it also results in an increased latency of saccades to the target for subjects who do not move their eyes towards the onset.

The present results provide evidence that the novelty of the onset modulates oculomotor capture. Participants in the present study developed a task set concerning the target, the stimulus displays, and the timing of events in a trial. Since an onset was not presented in the first half of the experiment, no information concerning the onset was part of the task set. On the first trial on which an onset was presented (the surprise onset trial), it captured participants' attention; 28% of the participants moved their eyes toward the onset on this trial. Since latencies of correct saccades to the target also revealed an effect of the surprising onset distractor, it is plausible that the onset captured attention in a stimulus-driven fashion, but some of the participants were able to refrain from executing a saccade to the onset. We propose that as the onset presentation was repeated on subsequent trials information concerning the onset was included in participants' task set. That is, participants realized that an onset was being presented and that this onset was task irrelevant. With this updated task set, participants were able to better ignore the onset and to inhibit the execution of a saccade in its direction.

It should be noted that the present results do not allow us to distinguish between the effect of a surprising onset and the effect of a surprising new object; the surprising event is both a luminance onset and the appearance of a new object at a previously unoccupied location. The purpose of the present study was not to examine the specific stimulus properties resulting in capture, but the degree to which surprise modulates capture.

Despite the overwhelming evidence that onsets have a strong effect on attention and eye movements (e.g., Irwin et al., 2000; Theeuwes, 1995; Theeuwes et al., 1998, 1999; Yantis, 1996), there is little consensus concerning the cause of this effect. While Theeuwes (1991, 2004) has argued that the effect of onsets is stimulus driven and cannot be overridden by top-down search strategies, others have maintained that the effect of onsets is contingent on top-down search strategies (e.g., Bacon & Egeth, 1994; Folk, Remington, &

Johnston, 1992; Gibson & Kelsey, 1998). For example, Gibson and Kelsey (1998) have suggested that features that signal the appearance of the task-relevant target display capture attention. In the oculomotor capture task the onset is typically presented simultaneously with the colour change of the distractors that defines the target location. Therefore, the onset is to some extent task relevant because it signals the appearance of the target. This temporal task relevance of the onset suggests that the effect of the onset might not be completely stimulus driven. However, in the present study, the onset has its greatest effect on performance when it is not part of participants' task set. That is, on the surprising onset trial participants are not aware that the onset distractor will temporally signal the presentation of the onset. Therefore, this initial capture effect is not contingent on the task-related knowledge concerning the onset and can be considered a stimulus-driven effect.

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