
Perception in the absence of attention: Perceptual processing in the Roelofs effect during inattentional blindness

William B Lathrop, Bruce Bridgeman§, Philip Tseng#

Electronics Research Laboratory, Volkswagen Group of America, 500 Clipper Drive, Belmont, CA, USA; e-mail: brian.lathrop@vw.com; § Department of Psychology, University of California, Santa Cruz, CA, USA;

Institute of Cognitive Neuroscience, National Central University, Jhongli, Taiwan

Received 26 October 2010, in revised form 4 September 2011

Abstract. We present two experiments that examine sensory processing during conditions of inattentional blindness. A large rectangular frame that normally induces a Roelofs effect can go unreported due to inattentional blindness. Even when participants fail to report the frame, they mislocalize an attended target in a way consistent with having processed the frame. A more demanding visuospatial distractor task can increase inattentional blindness during conditions of divided attention, but has no effect on the spatial mislocalization illusion. Our results support theories that postulate a significant amount of perceptual processing in the absence of attention.

1 Introduction

A number of experiments have shown that if one is engaged in an attentionally demanding task, and a highly visible yet unexpected (stimulus) event occurs, one may completely fail to notice this event (eg Becklen and Cervone 1983; Mack and Rock 1998; Moore and Egeth 1997; Neisser 1979; Neisser and Becklen 1975; Newby and Rock 1998; Stoffregen et al 1993). Mack and Rock (1998) call this phenomenon inattentional blindness (IB). It has been shown to occur for many categories of stimuli, even in those situations wherein the observer is fixating on the location of the stimuli's appearance. Across many experiments, testing thousands of participants, Mack and Rock found failures to report the unexpected appearance of squares and other geometric forms, words, color singletons, and even stimuli that moved (ie stroboscopic motion). Importantly, when the same stimuli were presented on subsequent trials, participants overwhelmingly reported their appearance.

Some researchers have proposed that IB reflects a failure in perceptual processing (see Mack et al 1992; Palmer and Rock 1994; Rock et al 1992a). Others, however, argue that the unreported events in these experiments were perceptually processed, but went unreported because of memory failure (see Moore and Egeth 1997; Wolfe 1999). In order to address these competing hypotheses, the following experiments use an online measure to assess sensory processing at the moment of stimulus presentation during conditions of IB. That is, the online measure assesses the impact on perception during the moment when the stimulus is presented, rather than depending on a report from the participant after some time interval. Memory, therefore, is not crucial in order to observe the processing of such items. To this end, the present study uses the induced Roelofs effect, a briefly-presented frame that shifts people's spatial reference, to tease apart the roles of implicit processing and memory in IB (Dassonville and Bala 2004; Dassonville et al 2004). The Roelofs effect has been proven useful in studying implicit perceptual processes (Bridgeman et al 1997), and its use of an online measure is suitable for the present study.

The findings of Moore and Egeth (1997) are particularly relevant to the present discussion. They showed evidence of perceptual grouping via similarity for unreported items presented during conditions of IB. In their experiment, on some trials

they presented parallel lines, one above the other, among an array of random dot elements. The primary task, also called the distractor task, was simply to judge which of the two lines was longer. On an unexpected (inattention) trial, however, the background elements formed an illusion-inducing pattern. That is, the background elements and parallel lines formed either a Müller-Lyer or a Ponzo illusion. Moore and Egeth found that, even though participants often failed to report the identity of these patterns on inattention trials, the illusions nonetheless biased participants' line judgments. Note that this is somewhat different from the IB reported in many of Mack and Rock's (1998) experiments. First, Mack and Rock's inattentionally blind participants were often unable to report anything about the unexpected stimulus, unable to select the stimulus on forced choice tests, and often unable to even guess that anything else in addition to distractor items had been presented during the inattention trials. In contrast, participants in Moore and Egeth's experiments were quite aware of the presence of the background elements on inattention trials. Participants' failures were in reporting the identity (ie pattern) formed by these elements.

In the present study, experiment 1 investigates whether a large illusion-inducing stimulus like that used by Moore and Egeth (1997) can suffer a qualitatively similar IB, like that found in many of Mack and Rock's (1998) experiments. More important, this experiment also tests whether this stimulus will still produce its illusory effects if it goes unreported. Experiment 2 examines the relationship between IB and attention. That is, a number of experiments suggest that changing the demands of the distractor task can impact reporting unexpected events during conditions of IB (see Neisser 1979; Neisser and Becklen 1975; Simons and Chabris 1999). Experiment 2, therefore, places greater demands on visuospatial resources by increasing the difficulty of the distractor task.

To reiterate, the current experiment will investigate two primary questions: (i) Can a large illusion-inducing stimulus, presented unexpectedly, go unreported? (ii) If the large illusion-inducing stimulus goes unreported, will it still impact perception? A positive answer to question (i) and a negative answer to question (ii) would suggest the IB in this experiment is due to a failure in perceptual processes. Alternatively, positive answers to questions (i) and (ii) would suggest that the IB observed in the following experiments does not eliminate processing, and thus implicating memory failure as the more likely cause of this phenomenon.

2 Experiment 1

2.1 Method

2.1.1 Participants. Seventy-nine participants, ranging in age from 17 to 24 years, took part in this experiment. All had normal or corrected-to-normal vision. Participants were recruited from the University of California at Santa Cruz (UCSC) undergraduate psychology pool, and were naive as to the purpose of the experiment. Students received partial course credit for participating in this experiment.

2.1.2 Apparatus. Participants were seated in darkness 50 cm from a 24 cm × 30 cm (27 deg × 34 deg) color monitor running at a 75 Hz. Stimuli were generated with PsyScope experimenter software on a Macintosh computer. Participants used a button box for making responses. The button box was placed beneath the display, such that each corresponding button was located directly beneath its respective target position (see figure 1). During all phases of this study, the participant's head was stabilized with a chin-rest.

During training trials (see section 2.1.3), the target appeared at -8, -4, 0, 4, or 8 deg from the participant's midline at eye level. These locations corresponded to target positions 1, 2, 3, 4, and 5, respectively. The practice target was a white cross consisting

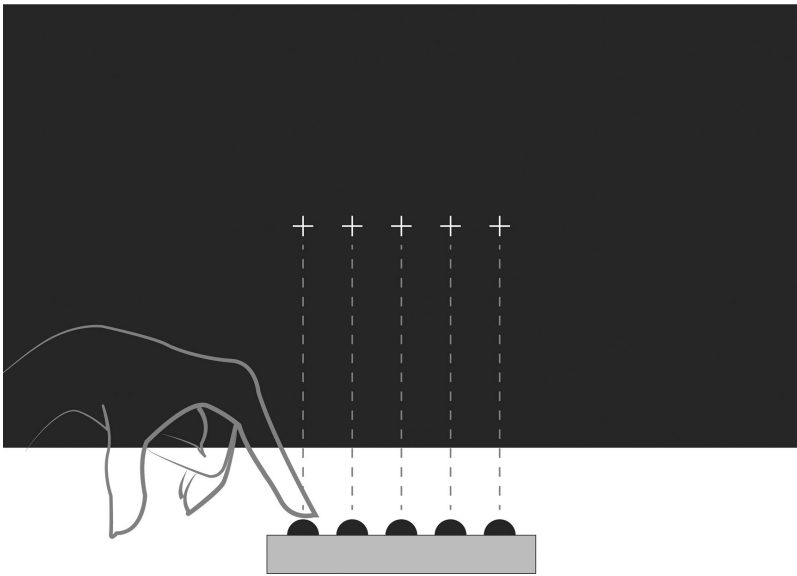


Figure 1. Display of five possible target positions and corresponding buttons used to indicate their positions. Depicted from left to right are target positions 1, 2, 3, 4, and 5, respectively.

of $2.85 \text{ deg} \times 2.85 \text{ deg}$ line segments. During experiment trials (see section 2.1.3), the target only appeared at positions 2, 3, and 4. Targets used in the experiment trials consisted of crossed horizontal and vertical line segments varying in dimensions from trial to trial (see table 1).

Finally, on trials 5, 10, and 12, the target was surrounded by a $21 \text{ deg} \times 9 \text{ deg}$ rectangular frame offset 4 deg to the right of the participant's straight-ahead (see figure 2). This rectangular frame was the critical stimulus. The consequences of this stimulus configuration during conditions when the frame can be consciously reported is an "induced Roelofs effect" (Bridgeman et al 1997). In short, this stimulus configuration biases the perceived location of the target within the frame in the direction opposite to the frame displacement.

Table 1. Dimensions of the vertical and horizontal segments of the target crosses used in experiments 1 and 2. Horizontal-1 is the length of the horizontal segment of the target cross in experiment 1. Horizontal-1 is also the length of the upper horizontal segment of the target cross used in experiment 2, while horizontal-2 is the length of the lower horizontal segment of the target cross used in experiment 2.

Trial	Segment/cm		
	vertical	horizontal-1	horizontal-2
1	2.00	3.50	3.50
2	2.00	1.25	3.50
3	2.00	3.50	1.75
4	3.00	1.75	1.75
5	2.00	3.50	1.25
6	2.00	1.75	1.75
7	2.00	1.25	3.50
8	2.00	1.50	3.50
9	3.00	1.75	1.75
10	2.00	3.50	1.25
11	2.00	4.00	4.00
12	2.00	3.50	1.25

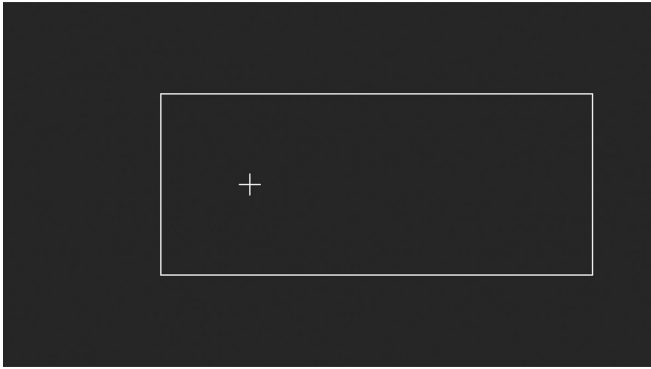


Figure 2. During each critical trial, a large laterally displaced rectangular frame was presented simultaneously with the target.

2.1.3 Procedures. The primary task required participants to indicate the remembered position of the target. Following this position judgment, participants were asked to perform a secondary task that required them to judge which segment of the cross was longer (eg the horizontal or vertical line segment). Together, these two tasks constituted the distractor task.

In addition to the presentation of the cross, participants were presented with an unexpected critical stimulus on trials 5, 10, and 12. Similar to Mack and Rock (1998), these trial types were categorized as the inattention, divided-attention, and full-attention trials, respectively. Trial 5 was categorized as the inattention trial, because it provided data about what could be reported when all expectations were removed and attention was being consumed by another task. Trial 10 was categorized as the divided-attention trial because participants now had a reason to expect that something in addition to the target cross might appear. Finally, trial 12 was the full-attention trial because the participant was explicitly told that something in addition to the target cross might appear on subsequent trials.

Prior to the experiment trials, participants completed twenty-five training trials in order to learn the five possible positions for target appearance. On each trial a target randomly appeared at one of the five positions. Upon target appearance, participants indicated its position by pressing the appropriate button. Participants were encouraged to take their time and try to perform as accurately as possible. To this end, the next trial did not advance until the participant responded correctly, and the target remained present until a response was given. Upon completion of the twenty-five training trials, participants could request an additional twenty-five training trials if they were still unsure about the task.

After the first set of training trials, participants went through an additional four training trials with the secondary distractor task. Participants underwent these trials to ensure that they understood how to properly respond to this additional task component. This was also done to keep the task relatively difficult. During these trials, in addition to indicating the position of the target, participants judged whether the vertical segment of the cross was longer or shorter than the horizontal segment. Thus, after target presentation and indication of its position, participants verbally gave their decision about the vertical segment of the cross by saying “longer” or “shorter”. After completion of these trials, participants began the experiment trials.

The presentation sequence for the twelve experiment trials is shown in figure 3. During the experiment trials the target could only appear at positions 2, 3, and 4. The target appeared at position 2 on five trials (trials 2, 5, 9, 10, and 12), position 3 on three trials (trials 3, 7, and 8), and position 4 on four trials (trials 1, 4, 6, and 11).

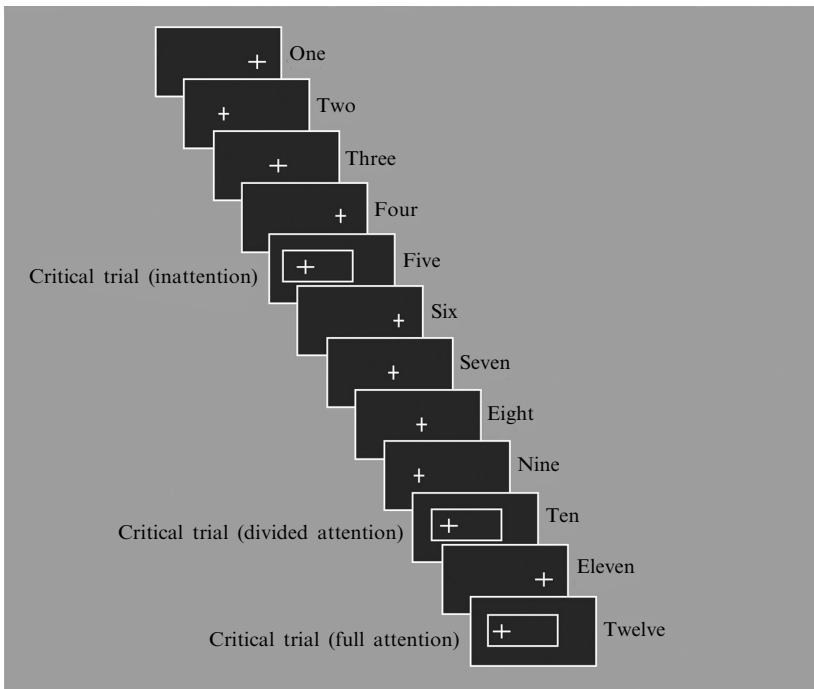


Figure 3. Overview of trial sequence.

Again, the unexpected frame appeared on trials 5, 10, and 12 (ie critical trials). The target was always at position 2 on these trials. Finally, trials 2 and 9 served as the primary control trials in this experiment. This is because the target on these trials was also located at position 2. Performance on trials 2 and 9 was thus averaged for each participant and used as the baseline reference in the following analyses. In other words, mean performance on trials 2 and 9 was compared to performance on trial 5 (inattention), 10 (divided attention), and 12 (full attention).

On each trial, participants were instructed to gaze forward at the darkened display. A fixation marker was not used, as it would have provided a point of reference for the subsequent position judgments. After this instruction, participants were asked if they were ready to proceed. After a positive indication by the participant, the experimenter initiated the trial. A 50 ms tone signaled the upcoming appearance of the target. The target then appeared for 100 ms and was immediately followed by a uniform mask for 500 ms. During the critical trials, both the cross and frame simultaneously appeared for 100 ms, followed by the mask.

Participants were not prompted for either position or length responses, unless they had forgotten, as they had already learned the sequence and nature of these responses on the previous training trials. This ended the sequence of events for non-critical trials. On trial 5 (the inattention trial), when the frame was present, the experimenter interrupted the experiment with a query to the participant. The query was used to see whether participants noticed the appearance of the frame around the target. The gist of the query was as follows:

“Uh! Um! I’m sorry, I think I accidentally hit the wrong key on that trial. I’m new at running this experiment and don’t have everything down yet. Did you happen to notice anything unusual on that trial? I mean, did you happen to notice the appearance of anything in addition to the cross?”

Following this query, participants answered the question and were given (without their knowledge) a positive or negative score according to their response. A positive score was given for replies that included the target words square, box, rectangle, frame, etc. A negative score was given to participants who replied that nothing in addition to the cross was presented.

A similar protocol was used on trial 10 (the divided-attention trial), but this time the wording was slightly modified to make it sound as if the experimenter had simply made another error in running the experiment. Again, participants' responses were scored without their knowledge. Following trial 10, participants were warned that another visual object in addition to the cross might appear on subsequent trials, and they should report this to the experimenter. On trial 12, the frame appeared for the third and final time and participants were again scored on their response. Following the completion of the twelve experiment trials, participants were debriefed about the purpose of the experiment.

2.2 Results

Table 2 shows the percentages of participants who failed to report the frame during inattention, divided-attention, and full-attention trials. Fifteen participants were removed from the data used in subsequent analyses for failing to report the frame on full-attention trials.⁽¹⁾ Also, seven participants had incomplete or improperly collected data, and were thus excluded. The remaining fifty-seven participants were classified according to their performance on reporting the appearance of the frame on the inattention, divided-attention, and full-attention trials. Participants who reported the frame on all three trial types were classified as reported-all ($n = 27$). Participants who failed to report the frame on the inattention trial, but reported the frame on the divided-attention and full-attention trials, were classified as missed-inattention ($n = 20$). Finally, those who failed to report the frame on the inattention and divided-attention trial types, yet reported the frame on the full-attention trials, were classified as missed-inattention and divided-attention ($n = 10$).

Table 2. Percentages of participants who failed to report the appearance of the frame on inattention, divided-attention, and full-attention trials. These rates are presented for all (ie raw data) and a subset of all participants (ie analyzed data).

	Raw data				Analyzed data		
	inattention	divided	full	<i>N</i>	inattention	divided	<i>N</i>
Experiment 1	53%	27%	15%	79	54%	19%	57
Experiment 2	59%	53%	25%	75	54%	36%	53

The following analyses assess participants' bias of judgments about target position and accuracy of (cross) segment discrimination. Bias was scored as the signed error between the participant's response and veridical position of the target. For instance, if the target appeared at position 4, and the participant's response was position 2, then a score of -2 was given. Accuracy of segment discrimination was scored as correct or incorrect for each participant across the twelve trials.

⁽¹⁾ It should be noted that many of these participants reported the frame on inattention and divided-attention trials. Failures to report the frame on the full-attention trial may have been due to blinking, not facing the monitor, or other unknown reasons. Because both the experimenter and participant were in darkness, the experimenter was not able to directly observe participant behavior. Nonetheless, because the full-attention trial serves as a reference for baseline performance, failure to report the frame on this trial makes the data difficult to interpret.

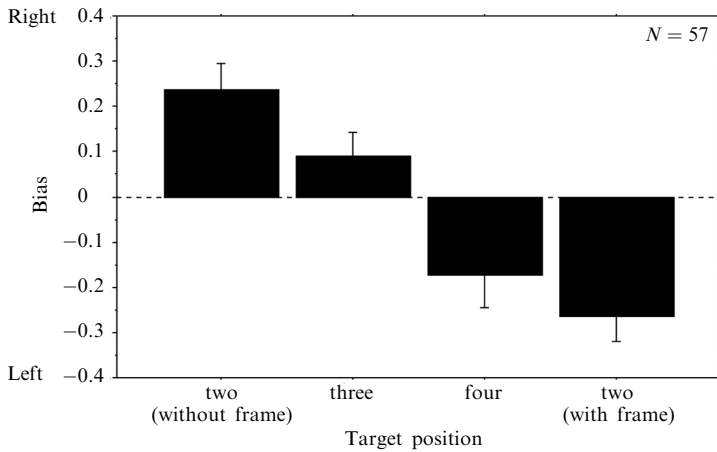


Figure 4. Mean bias across target position.

A one-way repeated-measures ANOVA was used to analyze bias across target position (2 with frame, 2 without frame, 3 and 4). Results showed significant differences in participants' judgments across target position ($F_{3,56} = 17.15$, $p < 0.01$). Mean bias estimates are shown in figure 4. An a-posteriori Scheffé test showed that judgments for position 2 without frame were significantly different from position 2 with frame ($p < 0.05$). This analysis suggests that the present stimulus conditions are sufficient to create an "induced Roelofs effect". The following analysis tests whether this effect is dependent upon one being able to report the appearance of the frame.

A 3×4 mixed-design ANOVA assessed participant bias for position 2 only as a function of participant classification (reported-all, missed-inattention, and missed-inattention and divided-attention) and trial type (control, inattention, divided-attention, and full-attention). There was a significant main effect for trial type ($F_{3,54} = 10.62$, $p < 0.01$) (see figure 5). No other effects were significant ($p > 0.05$). An a-posteriori Scheffé test showed that participants' mean biases for the inattention, divided-attention, and full-attention trials were significantly different from the control trials ($p < 0.01$). This analysis suggests that the bias caused by the offset frame did not depend on one being able to report the appearance of the frame, as there was no participant classification by trial type interaction.

Accuracy on the secondary distractor task was used to see whether or not performance on this task changed in a different manner for those who did and did not report

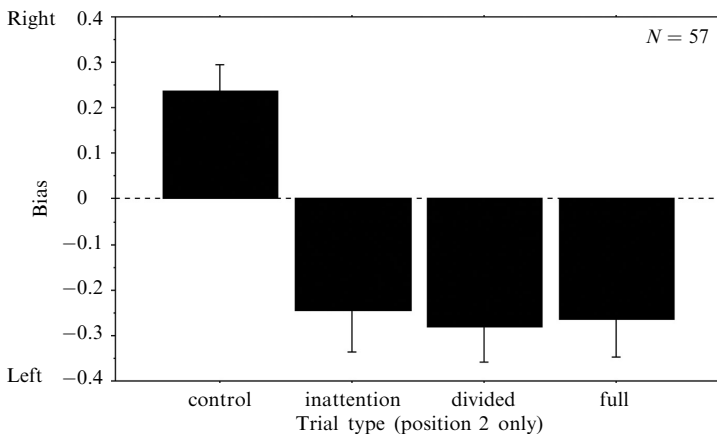


Figure 5. Mean bias across trial type.

the frame. The most relevant trial types in this analysis are the control and inattention trials, conditions when the frame was and was not reported. To this end, performance change for participants in the reported-all group was compared to the performance change for participants who did not see the frame on the inattention trials (ie missed-inattention, and missed-inattention and divided-attention groups).⁽²⁾ A between-subjects *t*-test showed no difference in performance change between the two groups ($t_{55} = 0.826$, $p > 0.05$). These results suggest that the frame did not impact performance on the secondary distractor task differently for those who did and did not report the frame.

2.3 Discussion

The current experiment investigated whether a large illusion-inducing stimulus presented unexpectedly could suffer similar IB to that reported by Mack and Rock (1998), and also whether such a stimulus would still influence perception. The results from this experiment provide positive answers to both questions. This experiment demonstrated that a large rectangular frame presented simultaneously with a target object went unreported on more than half of our inattention trials. Under increased levels of expectancy (ie divided-attention and full-attention trials), many more participants reported the appearance of the frame. Equally important is the fact that, even when the frame went unreported, the frame was perceptually processed to some extent. This was shown by its impact on perceived target position. Finally, performance on the secondary distractor task did not relate to one's ability to report the frame. Additional implications of these findings will be considered in the general discussion.

3 Experiment 2

Experiment 2 was similar to experiment 1, except that it used a more demanding visuo-spatial task for the secondary distractor task. This was done in order to better understand the relationship between attention and the IB shown in our experiment. If IB is related to attention, then tasks that engage more attentional resources should increase the chances of its occurrence.

The primary task for this experiment required participants to again indicate the position of a briefly presented target. The target, however, now consisted of one vertical and two horizontal segments. Thus, following the position judgment, participants made a discrimination judgment requiring an analysis of three cross segments. They had to decide whether the vertical segment of the cross was longer, shorter, or in-between the lengths of the two horizontal segments, as well as judge the target's position. Also, the same rectangular frame appeared on trials 5, 10, and 12 (ie inattention, divided-attention, and full-attention trial types, respectively).

3.1 Method

3.1.1 Participants. Seventy-five participants, ranging in age from 17 to 26 years, took part in this experiment. All had normal or corrected-to-normal vision. Participants were recruited from the UCSC undergraduate psychology pool. All participants were naive as to the purpose of the experiment, and received partial course credit.

3.1.2 Apparatus. The targets in the experiment trials consisted of one vertical and two horizontal line segments varying in length from trial to trial, as described above (see table 1). The two horizontal segments were positioned one above the other with approximately 0.9 deg separating the two. All other aspects of the experimental apparatus and visual stimuli were identical to those of experiment 1.

⁽²⁾Performance change was calculated by subtracting mean control performance (ie secondary distractor task performance on trials 2 and 9) from performance on the inattention trial. Thus, the dependent variable in this analysis was scored as -1, +1, or 0 for negative, positive, and null changes, respectively.

3.1.3 *Procedures.* The training phase was identical to that in experiment 1. After these trials, however, participants went through four additional training trials with the new secondary distractor task. This task consisted of trials wherein the participant discriminated whether the vertical segment of the cross was longer, shorter, or in-between the two horizontal segments. As in experiment 1, participants underwent these trials only to ensure they understood the nature and temporal sequence of responding on these trials. Following the completion of these four trials, participants began the twelve experiment trials.

The presentation sequence of the critical and non-critical trials remained the same in this experiment. Target positions, however, were changed in order to protect against possible confounds from display artifacts and target positioning. The target on critical and control trials was moved to the right side of the display (ie position 4), and also, the position of the target on other trials was randomly reassigned between positions 2 and 3. This resulted in targets appearing at position 2 on trials 1, 4, 8, 9, and 11; position 3 on trials 3 and 6; and position 4 on trials 2, 5, 7, 10, and 12. Trials 2 and 7 now served as the primary control trials. Performance on these trials was averaged in subsequent analyses.

3.2 Results

Table 2 shows the percentages of those who did not report the frame on the inattention, divided-attention, and full-attention trials. Both the raw data and data used in subsequent analyses are shown. Sixteen participants were removed because they did not report the frame on the full-attention trial.⁽³⁾ Five participants were removed for a successful report on the inattention trial, but an unsuccessful report on the divided-attention trials. This is because there was no meaningful way to categorize these participants, and there were too few of them for any meaningful analyses. Finally, one participant had incomplete data. The remaining fifty-three participants were classified with the same scheme used in experiment 1. The reported-all, missed-inattention, and missed-inattention and divided-attention groups consisted of twenty-five, nine, and nineteen participants, respectively.

A χ^2 test for independence was used to assess whether there was a difference in the frequency of IB between experiments 1 and 2 for both inattention and divided-attention trial types. The analysis of IB rates for the inattention trials showed that there was no significant difference between experiments 1 and 2 ($\chi^2_{1,110} = 0.027, p > 0.05$). The analysis of IB rates for the divided-attention trials revealed a marginal difference in IB between the two experiments ($\chi^2_{1,110} = 3.79, p = 0.052$). These results suggest that the secondary distractor task used in experiment 2 increased the likelihood of not reporting the frame on divided-attention trials; however, it had no impact on the inattention trials.

A one-way repeated-measures ANOVA was used to analyze bias across target position (4 with frame, 4 without frame, 2 and 3). Results showed significant differences in participants' judgments across target position ($F_{3,52} = 30.83, p < 0.01$) (see figure 6). An a-posteriori Scheffé test showed that the difference between positions 4 with frame and 4 without frame was significant ($p < 0.05$). This analysis suggests that the present stimulus conditions are sufficient to create an "induced Roelofs effect". The following analysis tests whether this effect is dependent upon one being able to report the appearance of the frame.

⁽³⁾In experiments 1 and 2 a high percentage of participants failed to report the frame on full-attention trials. We believe that this might have been due to participants still being engaged in additional tasks during these trials (ie still performing the distractor task). We tested this hypothesis by having twenty-four participants perform the experiment 2 protocol through trial 4; however, immediately following trial 4, participants were instructed to ignore both the primary and secondary distractor tasks. Further, participants were told that something in addition to the cross would appear on the next trial. Results showed that only one participant failed to report the appearance of the frame under these conditions.

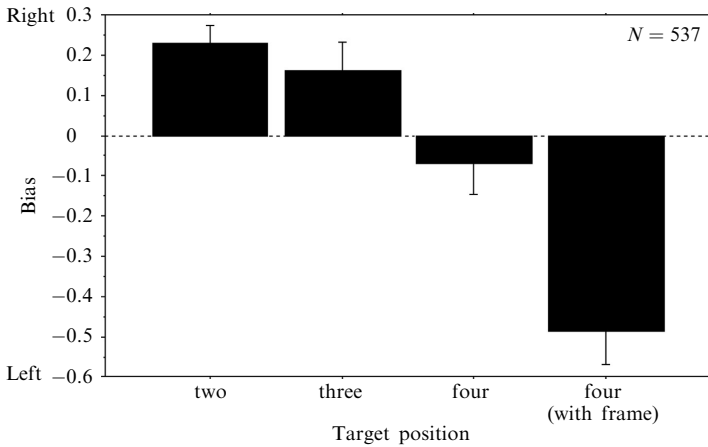


Figure 6. Mean bias across target position.

A 3×4 mixed-design ANOVA analyzed bias for position 4 as a function of participant classification (reported-all, missed-inattention, and missed-inattention and divided-attention) and trial type (control, inattention, divided-attention, and full-attention). This analysis showed a significant main effect for trial type ($F_{3,50} = 9.13, p < 0.01$) (see figure 7). All other effects were non-significant ($p > 0.05$). An a-posteriori Scheffé test showed that the mean bias for the control trials was significantly different from the mean bias estimates in the inattention, divided-attention, and full-attention trial types. All other mean comparisons were non-significant ($p > 0.05$). As in experiment 1, this analysis suggests that the frame had a significant impact on the perceived position of the target, and this effect did not depend on one being able to report its appearance.

Finally, we again assessed accuracy on the secondary distractor task to see whether performance on this task changed in a different manner for those who did and did not report the frame. As in experiment 1, the two trial types of interest were the control and inattention trials. A between-subjects t -test was used to see whether there was a difference in mean performance change between the two groups. Results showed no differences between the two groups ($t_{52} = 1.10, p > 0.05$). These results suggest that neither group's performance on the secondary distractor task was impacted by the appearance of the unexpected frame.

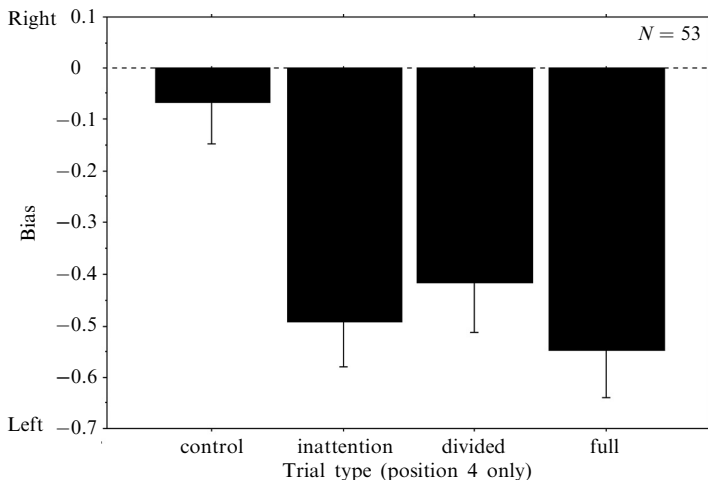


Figure 7. Mean bias across trial type.

3.3 Discussion

Experiment 2 shows a pattern of results similar to experiment 1. Over half of the participants failed to report the appearance of a large rectangular frame when presented unexpectedly. When cued to the possibility that something in addition to the target could appear during a trial, they were more successful at reporting the frame. This increased success, however, was somewhat attenuated in this experiment because of the increased demands of the secondary distractor task. That is, participants showed increased IB on the divided-attention trials in this experiment. The most important finding, however, was the corroborating evidence that, even when participants failed to report the frame, it still impacted the perceived position of the target. Finally, the analyses give no indication that performance on the secondary distractor task was impacted by one's ability to report the frame. Additional implications of these findings are considered in the next section.

4 General discussion

Two experiments employed a hybrid approach to the analysis of processing during conditions of IB. We characterized this as a hybrid approach because our method (a) drew from Moore and Egeth's (1997) illusion-inducing stimulus (on-line) paradigm, and (b) used Mack and Rock's (1998) criterion for IB. We asked the questions: (i) Can a large illusion-inducing stimulus presented unexpectedly go unreported due to IB? (ii) If that stimulus goes unreported, will it still impact perception? (iii) Is the frequency of IB in this task domain impacted by manipulations of available attentional resources?

We provide positive answers to the first two questions. These experiments show that a large rectangle presented around a small target cross will often go unreported when presented during conditions of high cognitive load. This result is consistent with similar findings showing that much smaller stimuli often go unreported when presented unexpectedly (see Mack and Rock 1998). Our experiments also show no differences in perceptual mislocalizations between those who did and did not report the illusion-inducing stimulus. Experiment 2 shows that a more demanding visuospatial distractor task may increase IB under some conditions. Specifically, our results show that a more demanding task may have a negative impact on reporting the critical stimulus during states that Mack and Rock (1998) characterize as diffuse or divided attention. It is not entirely clear, however, why the more demanding visuospatial distractor task did not have an impact on the inattention trials. Perhaps the frequencies observed on the inattention trials in these experiments represent a ceiling effect for the current stimulus configuration and/or experimental conditions. Future research should investigate the impact of variable visuospatial demands on IB in this task domain. Finally, our results show that the unexpected appearance of the frame did not have a differential impact on the secondary distractor task performances for those who did and did not report the frame.

In many previous IB experiments the unreported targets have been small and non-salient compared to the distractor stimuli. That is, much of the energy in the display has often been in the distractors. Our design, in contrast, puts a much greater percentage of the total stimulus energy in the unperceived test stimulus (ie the frame). Despite the size of the test stimulus, we found a high rate of failure to report it. Moore and Egeth (1997) also used a large test stimulus, but its presence was detected by participants—only the identity of the stimulus was masked. Therefore, the present study is the first demonstration wherein the stimulus that dominates the energy distribution can remain unreported in the majority of trials. Further, this large stimulus affects the perceived position of a much smaller probe similarly whether it is detected or not, implying that perceptual detection and pickup of spatially useful information are separate processes.

4.1 *Extent of processing for the Roelofs's frame*

The extent of perceptual processing in the absence of attention has been widely debated. For about the last fifty years, the debate has volleyed between those who propose high and low degrees of organization in the absence of attention (eg Baylis and Driver 1993; Broadbent 1958; Deutsch and Deutsch 1963; Mack et al 1992; Palmer and Rock 1994; Rock et al 1992a).

Those who favor high degrees of organization point to evidence of object-based attentional selection. For instance, Baylis and Driver (1993) found benefits in performance when judgments were made about two parts of the same object rather than two parts from different objects (see also Duncan 1984; Kahneman and Henik 1981; Kahneman et al 1983). Those who take the position of low degrees of organization point to the fact that simple Gestalt grouping processes, initially thought to occur very early in the information processing sequence of events, have been shown to occur only after processes that mediate some categories of perceptual constancy. For instance, Rock and Brosgole (1964) showed that shape perception is resolved prior to grouping by proximity (see also Rock et al 1992b). Later work by Moore and colleagues (Moore et al 2003, 2004) addressed this topic more precisely within the context of IB. With clever uses of perceptual completion of surfaces and the Simon effect, these authors observed successful surface completion, but no Simon effect when stimuli are unattended in IB. These results suggest that unattended stimuli in IB are processed enough for perceptual surface completion, but do not reach far enough to interfere with response selection (Simon effect).

The current study also complements the findings of Moore and colleagues (Moore et al 2003, 2004). For example, it is difficult to see how the induced Roelofs effect could occur without figure/ground segmentation (see Palmer and Rock 1994), which is consistent with the surface completion results from Moore et al (2003). In addition, the current results contrast nicely with Moore et al's (2004), because both the Roelofs and Simon effects require spatial representations to operate, but only the Simon effect involves response-end processes (Lo and Yeh 2008), which dissociates the positive and negative findings between the current study and the Moore et al (2004) study, respectively. Further, because the illusion produces biases in perceived position, one could argue that attention is engaged after those processes mediating position analysis. Lastly, the present findings show that unconsciously processed stimuli can alter our subjective midline and spatial frame of reference (see Dassonville and Bala 2004; Dassonville et al 2004). Taken together, these results suggest that unconscious processing of peripheral stimuli occurs rather early in perceptual processing. Future research should investigate more systematically the depth and extent of unconscious perceptual processing that can be said to occur during conditions of IB.

4.2 *Inattention blindness and other phenomena of unconscious processing*

In the past decade the debate concerning the impact of attention on perceptual processing has been reinvigorated by the (re)discoveries of change blindness (CB), the attentional blink (AB), and IB. Research on these phenomena show some startling consequences for perception when attention is removed from the visual experience. Change blindness shows that one may fail to notice highly visible scene changes made during an eye movement, screen flicker, mud splash, or scene cut (eg O'Regan et al 1999, 2000; Rensink et al 1997). The attentional blink shows that, if one is processing one target embedded in a rapid temporal display of many distractor items, another target (ie a probe) presented about a quarter-second later will go unreported (eg Joseph et al 1997; Mack et al 2002).

Similar to IB, studies have shown that unreported (instead of unattended) stimuli in CB and AB can also be processed to certain level below the threshold of explicit

response selection. For example, in CB participants' eye movements linger around an unreported change longer (Hollingworth 2003), and can guess the change better than chance when prompted (Fernandez-Duque and Thornton 2000; Tseng et al 2010a, 2010b; but see Mitroff et al 2002, for an alternative account of the same phenomenon; for a review from both perspectives, see Bridgeman and Tseng 2011, and Hannula et al 2005). In AB, studies also show that semantic and numerical information are processed, although masked targets are not consciously perceived (Hsu et al 2010; Railo et al 2008). Neuroimaging evidence is scarce, but does exist for CB (Fernandez-Duque et al 2003) and AB (Luck et al 1996). On the surface level, these blindness phenomena seem very similar. However, the stimuli from each paradigm (especially in CB) vary so widely that a simple generalization is not warranted. Therefore, the variety of complex stimuli from CB have generated different findings that suggest CB can be a result of failure in encoding (Hollingworth and Henderson 2002; Tseng et al 2010a, 2010b), visual memory (Wolfe 1999), or retrieval and comparison (Henderson and Hollingworth 2003). For instance, one might have encoded the item into memory and simply forgotten it during the interval between stimulus and response. Alternatively, the stimulus may never have been encoded into memory because attention may be required to mediate the perception-to-memory exchange. Distinguishing between memory and perceptual mechanisms as an explanation for IB, as well as other phenomena such as CB and AB, requires caution on the researchers' part.

Finally, we address some concerns with research on IB and related phenomena. One concern pertains to the relationship between attention and consciousness, or rather, inattention and lack of consciousness (awareness). The ongoing debate has centered on whether these terms mean the same thing or are different cognitive processes. Some would argue that attention and consciousness are the same cognitive process (eg O'Regan and Noe 2001). Others would argue that attention and consciousness are distinct processes with different neural mechanisms (eg Koch and Tsuchiya 2007). For example, consciousness in the absence of attention can be observed when participants are flashed images for moments too brief for top-down attention to play a role in processing. Empirical evidence comes from Mack and Rock's study (1998) where they flashed images for a very brief, 30 ms, to participants and it was shown that the gist of the scene could still be reported. A more moderate point of view (Dehaene et al 2006) suggests that attention and consciousness are, although different, inextricably interwoven because attention serves as a gateway to consciousness. Naccache (2002) has shown priming by a masked (invisible) word only when the participant can allocate attention to the task. When attention cannot be allocated to the task the prime-target pair priming fails to occur.

To place the present findings in a broader theoretical context, it is necessary to define what state of inattention and consciousness is achieved here, as well as the strength of the stimulus (eg Dehaene et al 2006; Koch and Tsuchiya 2007). We believe the unconscious condition has been achieved given that many participants were unable to report the identity of the stimulus on the inattentive trial, but were easily able to report it on subsequent trials. We also believe that a state of inattention was achieved according to the definition of the phenomenon outlined by Mack and Rock (1998). That is, participants in our experiment didn't simply fail to report the identity (ie pattern) formed by the rectangle on the inattention trials but, rather, they failed to report that anything other than the target had been present. This inattentive and unconscious state of processing is best categorized as the "preconscious" state of processing (Dehaene et al 2006), where bottom-up strength is fairly strong (the visible frame) but top-down attention is absent, thus leading to unawareness.

Neuroimaging evidence suggests that the conscious state of processing involves parieto-prefrontal activation and late amplification of posterior activity (Dehaene et al 2006). In contrast, only posterior activity is observed when people do not consciously

perceive a changed stimulus (Fernandez-Duque et al 2003; Pourtois et al 2006), and artificial interference with posterior parietal activity can induce unawareness of visual changes (Beck et al 2001; Tseng et al 2010a, 2010b). Patients with unilateral neglect, where parietal damage causes a loss of awareness for visual events occurring in the visual field on the contralesional side, also show extensive perceptual processing such as color/form extraction (Driver and Mattingley 1998) and image segmentation/completion (Mattingley et al 1997) in the absence of attention and/or awareness. In terms of frontal activity, stimuli that are processed but reported in AB also fail to activate the prefrontal activity that is usually present when stimuli are perceived and reported (Marois et al 2004). Therefore, it seems that any interference or absence of activities from the fronto-parietal network can induce a state of preconscious processing, which is likely the underlying neural mechanism of the present findings.

One last concern with this research is that IB relies on only a single inattention trial collected from each participant. This is problematic because a single trial is useless for disentangling bias and criterion effects. This makes it plausible that the unreported events in these experiments are seen on the inattention trials, but that participants are simply unwilling to report them (see Rensink 2000). Demand characteristics might suggest to the participant that the only task of any importance has already been outlined, and any straying from this task might suggest to the experimenter ineptness on the part of the participant. An experiment by Haines (1991) provides a plausible rebuttal against this explanation. The experiment, performed in an aircraft simulator, was designed to investigate the use of heads-up displays during the landing phase of flight. (Heads-up displays project flight information directly on the windshield of the aircraft, allowing the pilot to view this information and the outside world simultaneously.) Just prior to landing, a large airplane was placed at the point of touchdown in the center of the runway. Astonishingly, 25% of experienced pilots in this experiment failed to notice this unexpected runway incursion and proceeded to land their aircraft. Further, the pilots failed to report this event upon being queried about it after landing. This 25% IB rate makes the argument of demand characteristics implausible, as the argument implies that 25% of the experienced pilots would fail to report the appearance of an undeniably salient and very important visual event due to experimenter expectations. We contend that the critical stimuli in question are visible enough to override any criterion or bias shifts. Further, our experiments queried participants' perception on critical trials in such a way as to place the blame of any incidental mishaps (ie shifting attention away from the distractor task) squarely on the shoulders of the experimenter.

In conclusion, the results from these experiments show evidence for fairly extensive perceptual processing during conditions of IB. These results challenge assertions of highly limited processing in the absence of conscious awareness. Future research might take advantage of these types of perceptual illusions for systematically investigating the extent of perceptual processing during conditions of lack of conscious awareness.

References

- Baylis G C, Driver J S, 1993 "Visual attention and objects: Evidence for hierarchical coding of locations" *Journal of Experimental Psychology: Human Perception and Performance* **19** 451–470
- Beck D M, Rees G, Frith C D, Lavie N, 2001 "Neural correlates of change detection and change blindness" *Nature Neuroscience* **4** 645–650
- Becklen R, Cervone D, 1983 "Selective looking and the noticing of unexpected events" *Memory & Cognition* **11** 601–608
- Bridgeman B, Peery S, Anand S, 1997 "Interaction of cognitive and sensorimotor maps of visual space" *Perception & Psychophysics* **59** 456–469
- Bridgeman B, Tseng P, 2011 "Embodied cognitive and the perception–action link" *Physics of Life Reviews* **8** 73–85
- Broadbent D, 1958 *Perception and Communication* (London: Pergamon)

- Dassonville P, Bala J K, 2004 "Perception, action, and Roelof's effect: A mere illusion of dissociation" *PLoS Biology* **2** 1936–1945
- Dassonville P, Bridgeman B, Bala J K, Thiem P, Sampanes A, 2004 "The induced Roelofs effect: two visual systems or the shift of a single reference frame?" *Vision Research* **44** 603–611
- Dehaene S, Changeux J P, Naccache L, Sackur J, Sergent C, 2006 "Conscious, preconscious, and subliminal processing: a testable taxonomy" *Trends in Cognitive Sciences* **10** 204–211
- Deutsch J A, Deutsch D, 1963 "Attention: Some theoretical considerations" *Psychological Review* **70** 51–61
- Driver J, Mattingley J B, 1998 "Parietal neglect and visual awareness" *Nature Neuroscience* **1** 17–22
- Duncan J, 1984 "Selective attention and the organization of the visual world" *Journal of Experimental Psychology: General* **113** 501–517
- Fernandez-Duque D, Grossi G, Thornton I M, Neville N J, 2003 "Representation of change: Separate electrophysiological markers of attention, awareness, and implicit processing" *Journal of Cognitive Neuroscience* **15** 491–507
- Fernandez-Duque D, Thornton I M, 2000 "Change detection without awareness: Do explicit reports underestimate the representation of change in the visual system?" *Visual Cognition* **7** 324–344
- Haines R F, 1991 "A breakdown in simultaneous information processing", in *Presbyopia Research* Eds G Obrecht, L Stark (New York: Plenum) pp 171–175
- Hannula D E, Simons D J, Cohen N J, 2005 "Imaging implicit perception: promise and pitfalls" *Nature Reviews Neuroscience* **6** 247–255
- Henderson J M, Hollingworth A, 2003 "Global transaccadic change blindness during scene perception" *Psychological Science* **14** 493–497
- Hollingworth A, 2003 "Failures of retrieval and comparison constrain change detection in natural scenes" *Journal of Experimental Psychology: Human Perception and Performance* **29** 388–403
- Hollingworth A, Henderson J M, 2002 "Accurate visual memory for previously attended objects in natural scenes" *Journal of Experimental Psychology: Human Perception and Performance* **28** 113–136
- Hsu T Y, Cheng S K, Hung D L, Tzeng O J L, Juan C H, Tseng P, 2010 "The perseverance of numerical distance effect in attentional blink" *Perception* **39** 1526–1540
- Joseph J S, Chun M M, Nakayama K, 1997 "Attentional requirements in a preattentive feature search task" *Nature* **390** 805–807
- Kahneman D, Henik A, 1981 "Perceptual organization and attention", in *Perceptual Organization* Eds M Kubovy, J Pomerantz (Hillsdale, NJ: Lawrence Erlbaum Associates) pp 181–211
- Kahneman D, Treisman A M, Burkell J, 1983 "Perceptual objects and the cost of filtering" *Perception & Psychophysics* **33** 527–532
- Koch C, Tsuchiya N, 2007 "Attention and consciousness: two distinct brain processes" *Trends in Cognitive Sciences* **11** 16–22
- Lo S Y, Yeh S L, 2008 "Dissociation of processing time and awareness by the inattentional blindness paradigm" *Consciousness and Cognition* **17** 1169–1180
- Luck S J, Vogel E K, Shapiro K L, 1996 "Word meanings are accessed but cannot be reported during the attentional blink" *Nature* **383** 616–618
- Mack A, Pappas Z, Silverman M, Gay R, 2002 "What we see: inattention and the capture of attention by meaning" *Consciousness and Cognition* **11** 488–506
- Mack A, Rock I, 1998 *Inattentional Blindness* (Cambridge, MA: MIT Press)
- Mack A, Tang B, Tuma R, Kahn S, Rock I, 1992 "Perceptual organization and attention" *Cognitive Psychology* **24** 475–501
- Marois R, Yi D J, Chun M M, 2004 "The neural fate of consciously perceived and missed events in the attentional blink" *Neuron* **41** 465–472
- Mattingley J B, Davis G, Driver J, 1997 "Preattentive filling-in of visual surfaces in parietal extinction" *Science* **275** 671–674
- Mitroff S R, Simons D J, Franconeri S L, 2002 "The siren song of implicit change detection" *Journal of Experimental Psychology: Human Perception and Performance* **28** 798–815
- Moore C M, Egeth H, 1997 "Perception without attention: Evidence of grouping under conditions of inattention" *Journal of Experimental Psychology: Human Perception and Performance* **23** 339–352
- Moore M, Grosjean M, Lleras A, 2003 "Using inattentional blindness as an operational definition of unattended: The case of surface completion" *Visual Cognition* **10** 299–315
- Moore M, Lleras A, Grosjean M, Marrara M T, 2004 "Using inattentional blindness as an operational definition of unattended: The case of a response-end effect" *Visual Cognition* **11** 705–719

- Naccache L, 2002 "Unconscious masked priming depends on temporal attention" *Psychological Science* **13** 416–424
- Neisser U, 1979 "The control of information pickup in selective looking", in *Perception and Its Development: A Tribute to Eleanor Gibson* Ed. A D Pick (Hillsdale, NJ: Lawrence Erlbaum Associates) pp 201–219
- Neisser U, Becklen R, 1975 "Selective looking: Attention to visually significant events" *Cognitive Psychology* **7** 480–494
- Newby E, Rock I, 1998 "Inattention blindness as a function of proximity to the focus of attention" *Perception* **27** 1025–1040
- O'Regan J K, Deubel H, Clark J J, Rensink R A, 2000 "Picture changes during blinds: Looking without seeing and seeing without looking" *Visual Cognition* **7** 191–212
- O'Regan J K, Noe A, 2001 "A sensorimotor account of vision and visual consciousness" *Behavior and Brain Science* **24** 939–973
- O'Regan J K, Rensink R A, Clark J J, 1999 "Change blindness as a result of 'mudsplashes'" *Nature* **398** 34
- Palmer S, Rock I, 1994 "Rethinking perceptual organization: The role of uniform connectedness" *Psychonomic Bulletin & Review* **1** 29–55
- Pourtois G, De Pretto M, Hauert C A, Vuilleumier P, 2006 "Time course of brain activity during change blindness and change awareness: Performance is predicted by neural events before change onset" *Journal of Cognitive Neuroscience* **18** 2108–2129
- Railo H, Koivisto M, Revonsuo A, Hannula M M, 2008 "The role of attention in subitizing" *Cognition* **107** 82–104
- Rensink R A, 2000 "When good observers go bad: Change blindness, inattention blindness, and visual experience" *PSYCHE* **6** <http://psyche.csmonash.edu.au/v6/psyche-6-09-rensink.html>
- Rensink R A, O'Regan J K, Clark J J, 1997 "To see or not to see: The need for attention to perceive changes in scenes" *Psychological Science* **8** 368–373
- Rock I, Brosgole L, 1964 "Grouping based on phenomenal proximity" *Journal of Experimental Psychology* **67** 531–538
- Rock I, Linnet C M, Grant P, Mack A, 1992a "Perception without attention: Results of a new method" *Cognitive Psychology* **24** 502–534
- Rock I, Nijhawan R, Palmer S, Tudor L, 1992b "Grouping based on phenomenal similarity of achromatic color" *Perception* **21** 779–789
- Simons D J, Chabris C F, 1999 "Gorillas in our midst: Sustained inattention blindness for dynamic events" *Perception* **28** 1059–1074
- Stoffregen T A, Baldwin C A, Flynn S B, 1993 "Noticing of unexpected events by adults with and without mental retardation" *American Journal on Mental Retardation* **98** 273–284
- Tseng P, Hsu T Y, Muggleton N G, Tzeng O J L, Hung D L, Juan C H, 2010a "Posterior parietal cortex mediates encoding processes in change blindness" *Neuropsychologia* **48** 1063–1070
- Tseng P, Tuennermann J, Roker-Knight N, Winter D, Scharlau I, Bridgeman B, 2010b "Enhancing implicit change detection through action" *Perception* **39** 1311–1321
- Wolfe J M, 1999 "Inattention blindness", in *Fleeting Memories* Ed. V Colheart (Cambridge, MA: MIT Press) pp 71–94

ISSN 0301-0066 (print)

ISSN 1468-4233 (electronic)

PERCEPTION

VOLUME 40 2011

www.perceptionweb.com

Conditions of use. This article may be downloaded from the Perception website for personal research by members of subscribing organisations. Authors are entitled to distribute their own article (in printed form or by e-mail) to up to 50 people. This PDF may not be placed on any website (or other online distribution system) without permission of the publisher.