Implicitly perceived objects attract gaze during later free viewing

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Everyday life frequently requires searching for objects in the visual scene. Visual search is typically accompanied by a series of eye movements. In an effort to explain subjects' scanning patterns, models of visual search propose that a template of the target is used, to guide gaze (and attention) to locations which exhibit "suspicious" similarity to this template. We show here that the scanning patterns are also clearly influenced by implicit (unrecognized) cues: A backward masked object, presented before the scene display, automatically attracts gaze to its corresponding location in the following inspected image. Interestingly, subliminally observed words describing objects do not have the same effect. This demonstrates that visual search can be unconsciously guided by activated target representations at the perceptual level, but it is much less affected by implicit information at the semantic level. Implications on search models are discussed.

Keywords: eye position, priming, attention

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Introduction

Full comprehension of a complex visual scene requires scanning it with multiple eye movements which allow extraction of behaviorally important details using the high-resolution fovea. In his seminal study, Yarbus has shown that observers direct their gaze towards the most important aspects in a visual scene, and that these fixation targets change according to task demands (Yarbus, 1967). This type of behavior makes sense when considering it from an evolutionary perspective as for example, it allows better assessment of the condition of potential prey or predators.

Both explicit and implicit knowledge could be used by the gaze control mechanisms. But while we can clearly direct our gaze according to an explicit instruction, we are generally unaware of the fact that we constantly shift our gaze at about three times a second. Therefore, it is reasonable that gaze selection may typically rely on implicit rather than explicit representations of the visual world, especially since an online explicit visual representation of the world is likely to be fragmentary and short lived (Chun & Nakayama, 2000; Hayhoe, Shrivastava, Mruczek, & Pelzm, 2003; Neisser, 1967). Surprisingly little is known about the nature of these implicit representations. Several studies investigating visual search proposed a set of "implicit memory" mechanisms which are suggested to guide attention to ensure its efficient deployment (Chun & Nakayama, 2000). Such mechanisms are not necessarily under conscious control, nor does the observer need to have explicit access to the underlying content of the visual representations. For example, a study of priming effects in pop-out search showed that presentation of a target in one trial, automatically draws attention towards its features in the following trial, without effortful and conscious decision making (Maljkovic & Nakayama, 1994, 1996). Other studies have shown that implicit information about the layout of prior scenes may also guide attention, an effect termed contextual cueing (Chun & Jiang, 1998). Finally, it has been demonstrated that a briefly presented masked word (matching the target object), facilitates later change detection of the same target (Walter & Dassonville, 2005).

These studies, however, provided only indirect evidence for the guidance of attention as they only measured manual response time. Here, we utilize the fact that in natural viewing conditions, eye movements and attention are tightly coupled (Deubel & Schneider, 1996; Henderson, 2003), therefore, gaze position is a more direct measure of attention deployment.

We designed an experiment in which eye-movements were measured during a "change detection" search task. Other studies have used similar designs to investigate the relation between the exact eye position and successful detection (Henderson, Brockmole, & Gajewski, 2008; Hollingworth & Henderson, 2002; Hollingworth, Schrock,

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& Henderson, 2001; Hollingworth, Williams, & Henderson, 2001). In contrast to these studies, our goals were two-fold: first, to assess the degree to which the scanning pattern, prior to detection, is influenced by implicit priming; second, to find out what levels of representation are accessible to the gaze control processes.

Methods

Participants

Twenty seven (10 males) and 28 (8 males) naive undergraduate students (ages of 19 to 28) took part in one session of Experiments 1 and 2, respectively, in return for course credit. They all gave written informed consent and had normal or corrected-to-normal visual acuity by self-report. Experimental procedures were approved by the ethics committee of the Psychology department at Ben-Gurion University, Israel. One subject with exceptionally low detection performance (less than 50%) was discarded from further analysis.

Stimuli and experimental settings

Stimuli included 60 computer-generated (3D studio MAX; Autodesk, Inc, Montreal) indoor scenes. The scenes were comprised of 10 different sets of objects—each set included approximately 10 various objects belonging to one indoor scene (e.g. office, living room, garage and bedroom). Each set was accompanied by its matching "background", e.g. the walls and windows. Each set of objects was rendered in several spatial layouts to yield meaningful scenes (see Supplementary materials for example of "change blindness" clips). Scenes were rendered to a resolution of 1024 × 768 pixels and were converted to grayscale to avoid possible influence of variable colors on the measured behavior. The images were displayed on a 19-inches CRT monitor (Graphics Series G90fB, View Sonic, Los Angeles, USA), at a resolution of 1024 × 768 pixels with a refresh rate of 100Hz. The stimuli covered 34.3 × 25.8 of visual angle on the horizontal and vertical axes, respectively. Further descriptions of the stimuli are provided in the "Experimental design" section.

The experiments were conducted in a dimly lit room, subjects sat in front of a computer screen while their head was positioned in a chinrest. Subjects' eyes were located 60 cm from the computer screen. A video-based desktop-mounted eye tracker (Eye Link1000, SR Research, Ontario, Canada) with a sampling rate of 1000 Hz and a nominal spatial resolution of 0.01 degrees was used for recording eye movements. We used built-in programs provided with the eye tracker for calibration and validation purposes (5 points presented in a random sequence). The data analyzed in the present paper were obtained from recordings conducted with an average error of less than 1 degree. During the experiment, a fixation point appeared at the center of the screen before each trial. The subjects triggered the stimulus display when they were ready while fixating on a fixation point. The data obtained during this control fixation were used to correct for slow drifts of the eye tracker. If drift error was more than 2 degrees, a new calibration protocol was initiated. After every 20 trials subjects had a break which was followed by an additional calibration procedure.

Experimental design

Experiment I

Each trial began with a button press while subjects were fixating on a central fixation point. Next, a prime (2.9 × 2.9 degrees) was centrally presented for 30 ms, followed by a blank gray screen for 100 ms and then a mask was presented for 100 ms (exact timing parameters were determined in pilot studies). The prime's identity could either be the target in the following change detection task, or a distractor, that is, an object that would be present in the scene of the change detection task but would not change.

Each change detection scene had both target and distractor primes associated with it, but each subject was exposed to only one of the primes (target or distractor) per trial. Prime types for each trial were counterbalanced across subjects. After the prime and mask presentation, a gray screen appeared and subjects were instructed to indicate (via button press, i.e. "yes" or "no" answer) whether they recognized the object presented as the prime or not. Following the key-press (or a maximum of 2 seconds) a change detection task using the "flicker paradigm" (Rensink, 2000) was initiated. Two pictures of a scene, identical except for a difference in a single object (e.g., disappearance, translation, rotation or change in the brightness of an object), were repeatedly alternated in an ABAB fashion with a blank gray screen inserted between the two pictures (Figure 1). The alternations continued for a maximum of 30 seconds or were terminated earlier by the subjects (using a key press) if they detected the changed object. Next, a nine box grid was overlaid on one of the pictures of the change detection task and the subjects were required to indicate (via button press) the location of the changed object on the grid. A changed object could occupy more than one grid location and therefore all grid locations occupied by the changed object were treated as correct detections. In the final phase of the trial, participants were required to perform a two alternative forced-choice task regarding the prime: The two possible primes associated with a trial (target and distractor) were presented and the subjects indicated (using the designated keys on the keyboard) which of the two images was shown at the initial priming phase of the trial. Note that this part was performed after the

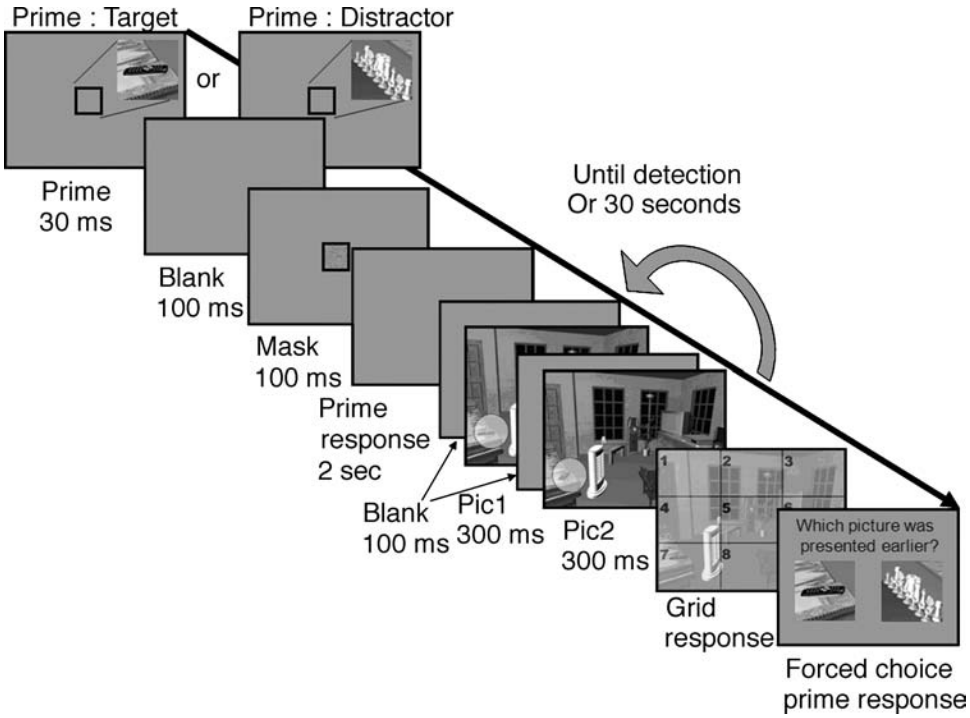

Figure 1. Experimental paradigm. An example of an experimental trial. At the beginning of each trial, one of two possible primes was presented, and followed by a mask after a fixed stimulus onset asynchrony. After a 2 sec period (in which the subjects had to indicate if they recognize the prime's identity) the change detection task was initiated. Two pictures, identical except for a difference in a single object (highlighted here by the white circle in the lower left corner of pic1 & pic2) were repeatedly alternated with a blank gray mask transient presented between the two. This was continued until target detection (indicated by key press) or terminated after 30 sec. Then, after reporting the general location (grid 1–9) of the changed target, the subjects indicated which prime was presented (out of two alternatives).

change detection task. Therefore, the subjects already knew which object had changed and might have been biased to choose it as the prime. To eliminate any performance advantage from such a bias, we used only two equi-probable prime options (target, distractor). So consistently choosing the changed object as the putative prime would have lead to 50% correct.

Experiment II

The design was identical to the design employed in Experiment 1 but here, the primes were words of the same objects that were used as primes in Experiment I (in Hebrew, Andalus font, width of 3.7 to 5.8 degrees and height of 1.9 degrees). Pilot studies were used to determine the contrast level of the word primes so that the overall number of implicit trials would be roughly equated across the two experiments (see details below).

Data analysis

Measures of implicit perception

In each trial two separate measures were obtained that could potentially be used to assess implicit perception of the primes. Immediately after the presentation of prime and its masking stimulus, the subjects responded by a button press (i.e. "yes" or "no" response) whether they recognized the prime. We term this task, which is subjective in its nature, an introspection task. Later, after completion of the change detection task of each trial, subjects performed a second task and indicated which of the two pictures appearing on the screen, was the prime that appeared at the beginning of the trial. We term this second task "forced choice task" and use it to sort out trials as explicit and implicit for further analysis. Specifically, explicit trials were defined as trials in which subjects chose the correct response in the forced choice task, suggesting that they were aware of the identity of the prime (though in some cases this correct choice could have been due to correct guessing). Implicit trials were defined as trials in which subjects provided an incorrect response in the forced choice response, indicating that they did not consciously perceive the prime. This is obviously an underestimate of the implicit trials, because some of the "explicit" trials were due to sheer guessing. Note that unlike previous studies, we categorized the trials as explicit or implicit regardless of the subjects' subjective response in the first introspection task. Due to this method of defining implicit trials, potentially, there are trials categorized as implicit for which subjects provided a correct response in the first task but an incorrect one in the second task. Such trials are perhaps not "purely" implicit in the sense that for these trials subjects might have some explicit, albeit incorrect, impression of the primes. Critically, the percentage of such trials is fairly small and does not differ between the first and second experiments (4.74 ± 0.88 and 4.52 ± 0.62 average and *SEM* percentage of trials for the image and word experiments, respectively). Moreover, even if these trials are excluded from the analysis, the overall pattern of results remains qualitatively the same. We further discuss the advantage of defining implicit trials solely on the basis of the forced choice task in the Discussion section (see Experimental task considerations).

Eye tracking

Fixation positions and saccades were defined using the following procedure: For each data sample, a built-in "event parser" of the eye tracker computed the instantaneous velocity and acceleration of the eye movement. A saccade was registered if these two values cross predefined thresholds (30 deg/s and 8000 deg/s2, respectively) for 2 or more samples (at 1 kHz) in a sequence. The saccade ended when the velocity or acceleration values were below the threshold (and remained so for a continuous period of 20 msec). The intervening episodes between saccades were defined as fixation events. The resulting trajectories were visually inspected to make sure that they produced adequate parsing of the eye-position samples to saccades and fixations.

Regions of interest

Two regions of interest (ROIs) were created for each trial, one for the target and the other for the distractor object (see Figure 2). Each region was defined as a square (5.5 × 5.5 degrees) surrounding the image patch containing the object. For each trial we analyzed the time it took the eyes to fixate for the first time on a point within the predefined ROIs. Then, we pooled the data across all "Primed target" and "Primed distractor" trials (see Figure 2) and performed statistical tests on the mean values across subjects. This was done separately for implicit and explicit trials.

Note that subjects often fixated on the changed object more than once before reporting that they detected the change. Specifically, subjects made 2.50 and 2.56 fixations on the target object (in Experiments 1 and 2, respectively) and 1.80 and 1.74 fixations on the distractor object (Experiments 1 and 2, respectively) before reporting the detection of the change. This mainly occurs because manual report of change detection often requires fixating on the target in both images comprising the change detection stimulus (Hollingworth & Henderson,

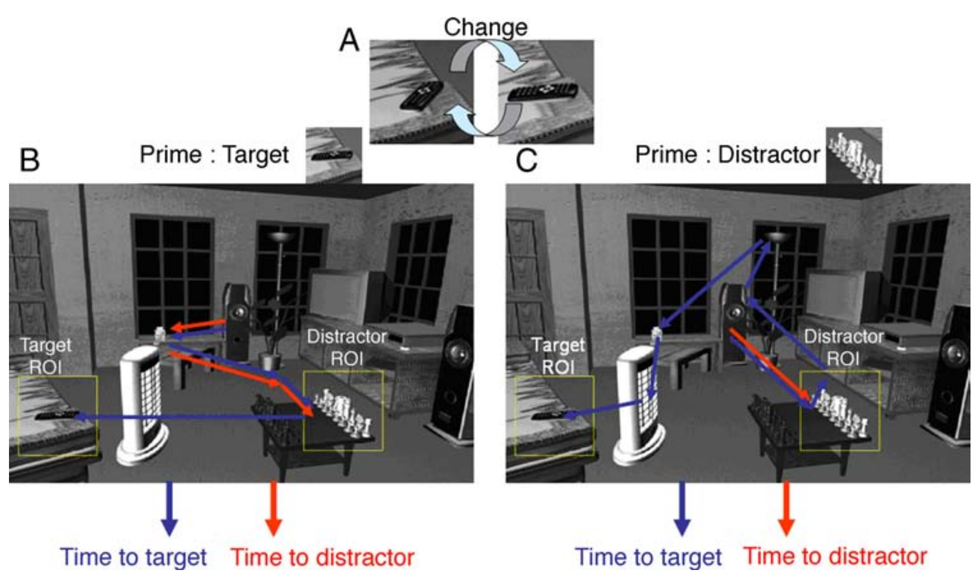

Figure 2. Analysis methods. Panel A shows the changed object of the change detection task in one trial. Panels B and C show examples of scanning patterns of trials with two different primes, either a prime which is the trial's target (B) or a distractor (C). Analysis was conducted separately for trials with primed target (B) and primed distractor (C). Note that since the change detection trials were never repeated, each subject saw only one prime version (B or C) for each unique trial (counterbalanced across subjects). For each trial we analyzed the time it took the eyes to fixate on a point located within the borders of the Region Of Interest (ROI) defined for the target and distractor (yellow square overlaid on the image, for presentation purposes). Two parameters were calculated: time until fixation on the target ROI and time until fixation on distractor ROI. In a minority of the trials one of the ROIs (usually the distractor) was not fixated. Such trials were not included in the analysis. We then compared the average "time to target" and "time to distractor" in trials with primed target and trials with a primed distractor.

2002). Therefore, the time until change detection (as reported manually) is composed of the time until the target is fixated for the first time and the time between the first fixation and change detection. The latter one is probably more related to the saliency of the change. The focus of the present study is on the guiding mechanisms elicited by the primes that *lead* to fixation on the target, and therefore analyzing the time until the first fixation on the target seems like the most appropriate measure.

Results

The goal of our experimental design was to study the influence of implicit visual processing on subjects' scanning patterns. We therefore examined the influence of briefly presented primes that could be either implicitly or explicitly perceived, on performance in a subsequent change detection task. First, we categorized each trial as "implicit" or "explicit" (see Methods section for details). Generally, in explicit trials, detection of the changed objects is expected to be faster, when encountering the target (as a prime) than when seeing the distractor as a prime. The empirical question here is whether a similar effect would also be found for implicit trials, thus indicating an effect of implicit perception on search performance (in terms of reaction time and eye movements).

Experiment 1

In 12% of the trials, the subjects did not indicate detection of the change using the key response or failed to indicate the correct position of the change. These trials were discarded from further analysis. Using the forced choice task, trials were categorized to explicit (76.9 ± 8.2% average and standard error) and implicit (23.1 ± 8.2%) trials. As mentioned before, this is obviously an underestimate of the truly implicit trials, because some of the "explicit" trials were due to sheer guessing (see Discussion—Experimental task considerations).

Reaction time analysis

Analysis of the mean reaction time for target detection revealed that when the prime was the sought-after target, it substantially shortened the time until change detection in both explicit and implicit trials (see Figure 3). A two-factor repeated measures ANOVA with *prime type* (target or distractor) × *perception type* (implicit or explicit) was conducted across subjects on the average response time (RT) in the change detection task. This analysis revealed significant main effect of prime type and perception type [$F(1, 26) = 20.8$, $p < 0.0002$ and $F(1, 26) = 4.8$, $p < 0.04$, respectively], such that RTs were shorter when the target was primed, compared to cases when the distractor was primed and target detection was faster during explicit trials than during implicit ones. The prime type × perception type interaction was not significant [$F(1, 26) = 0.68$, $p < 0.4$]. Simple effects analysis of prime type for the different perception types revealed that when the prime was the target object, it resulted in speeded change-detection both in explicit and implicit trials [one tailed paired *t*-test, $p < 0.00001$; $p < 0.05$; respectively] (Figure 3).

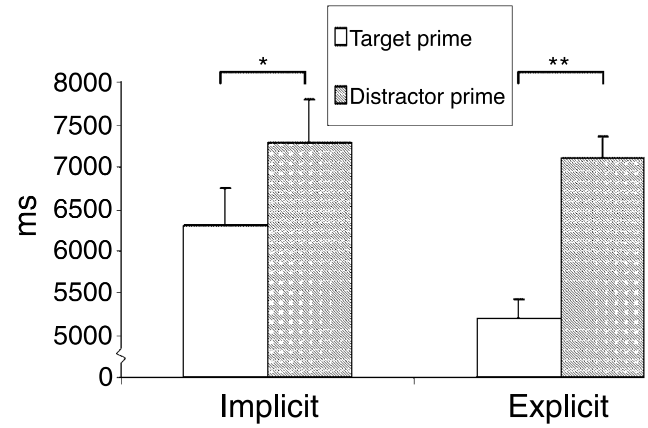

Figure 3. Reaction time in the change detection task depends on the prime image. Average reaction time across subjects (N = 27) shown separately for the 4 (2 × 2) classes of trials. These are categorized as trials in which the target was primed (target prime) and trials in which the distractor was primed (distractor prime), in cases when the prime was recognized (explicit trials) and when it was not recognized (implicit trials). Error bars denote standard error of the mean across subjects (*SEM*). One and two asterisks denote significance level of 0.05 and 0.001, respectively.

Distribution of response times

The analysis above was conducted on the subjects' average response time for the different trial types. One concern is that since typically reaction times are not symmetrically distributed, the mean might not represent correctly the overall performance. Furthermore, examining the distributions of reaction time measurements rather than just their means might reveal additional information on the strategies subjects use in attempting to find the changing target. Close examination of the response time (RT) distribution (pooled across all subjects) of the explicit vs. implicit trials shows that the commonest explicit trials have response time lower than 3 seconds (consisting mostly of trials in which the target prime was truly explicitly perceived) (Figure 4A). Examining the RT distributions within explicit trials (Figure 4B) reveals that the short latency trials are indeed the ones with primed target (rather than the distractor). Furthermore, there is a slight leftward shift of the distribution of the implicit target-primed trials with respect to implicit

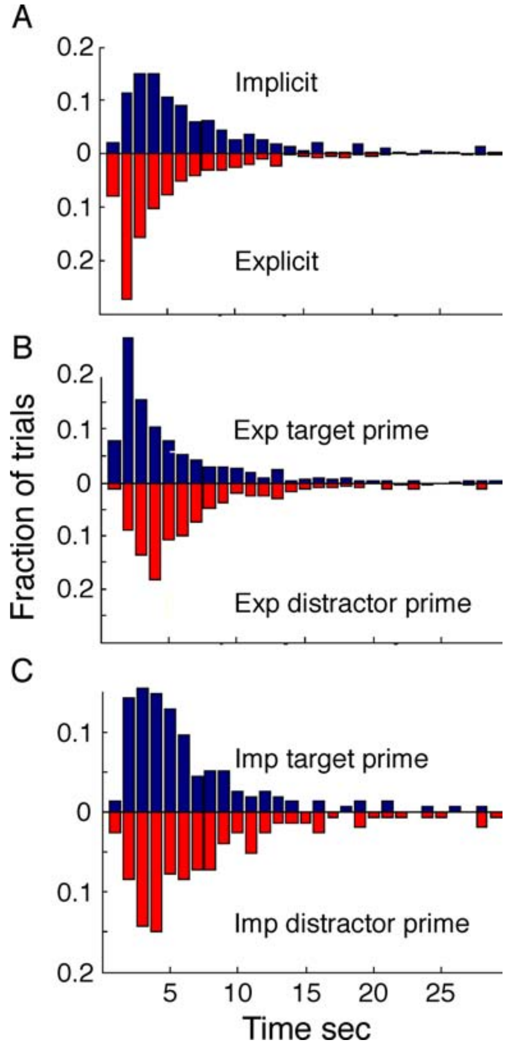

Figure 4. Histograms depicting the distributions of RTs in Experiment 1 (image primes). A) RTs of implicit Vs explicit trials. B) RTs within explicit (Exp.) trials, when the target was primed Vs when the distractor was primed. C) RTs within the implicit (Imp.) trials, when the target was primed Vs when the distractor was primed (For histograms of other dependent measures and for a similar analysis of Experiment II see Supplementary materials).

distractor-primed trials (Figure 4C), in accordance with the mean RT data (Figure 3). Similar results could also be seen in Experiment II (Figure S4) and for the eye movement measures (Figures S5 and S6). These distributions therefore verify that our results are not due to outliers.

Overall, these results demonstrate that primes influence detection performance even when they are only implicitly perceived. We next turn to analyzing the effect of primes on gaze position.

Eye movement analysis

The analysis of the time until the first fixation on the target revealed a prime-identity dependency (Figure 5), similar to its effect on the change-detection response time.

This analysis was conducted only for trials in which subjects both detected the change and fixated on the changed region at some point before the end of the trial (84.0 ± 14.5% of the trials, average and standard deviation across subjects). We first analyzed the sources of variation for the time until first gaze on the target ROI using a two-factor repeated measures ANOVA across the subjects pool. The ANOVA revealed a significant main effect of prime type [$F(1, 26) = 26.4$, $p < 0.0001$], which indicated that when the prime was the target object, the subjects' gaze was directed towards the changed object earlier than when the prime was the distractor. This analysis also revealed a significant interaction of prime type × perception type [$F(1, 26) = 4.3$, $p < 0.05$]. Analysis of the simple effect of prime type (target or distractor) for the different perception types (implicit or explicit) revealed significant effects in both conditions, although the effect was greater for the explicit trials [one tail paired *t*-test, $p < 0.0001$; $p < 0.03$, explicit and implicit trials, respectively] (see Figure 5).

Overall, these results are compatible with the reaction time data and show that gaze is attracted to the target even when the target-prime is only implicitly perceived.

Next, we analyzed the time until subjects first fixated on the *distractor* ROI. This analysis was conducted only for trials in which the change was detected and subjects fixated the distractor ROI before the end of the trial (57.7 ± 11.7% of the trials). The results show that when the distractor was primed, the eyes were directed toward the distractor object *earlier* than when the target was primed (Figure 6).

A repeated measures ANOVA was conducted on the average time for fixation within the distractor ROI and revealed only a significant main effect of prime type [$F(1, 26) = 15.1$, $p < 0.0008$], which indicated that when

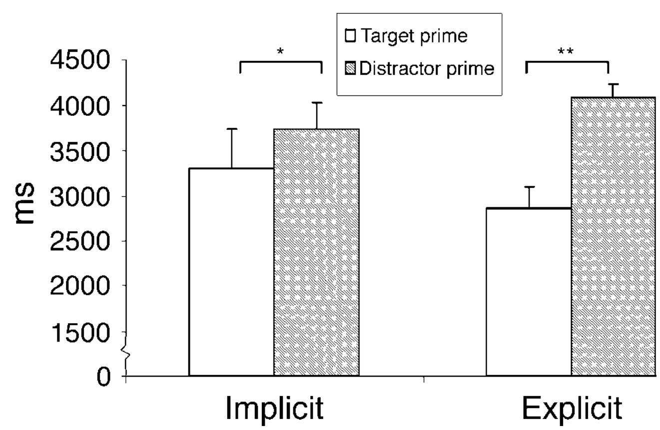

Figure 5. Time until fixation on the *target* depends on the image prime. Analysis of the average time (N = 27 subjects) to fixate on the target ROI (the changing object in the change-detection task). Trials in which the target was primed led to shorter target fixation times relative to trials in which the distractor was primed. This was true for both explicit and implicit priming trials. Conventions as in Figure 3.

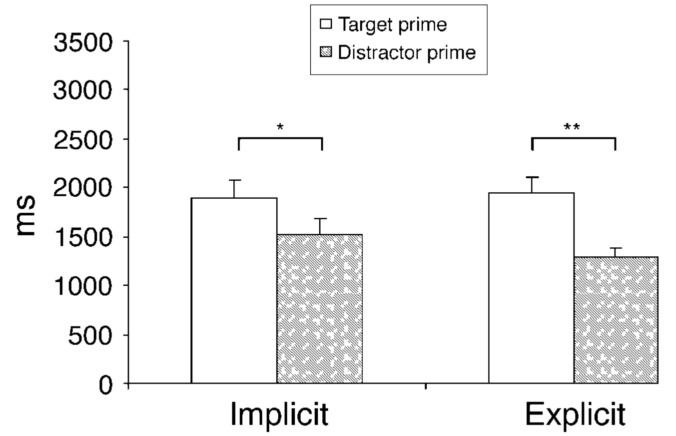

Figure 6. Time until fixation on the *distractor* region depends on the image prime. The figure depicts the average time until fixation on the distractor ROI in the different conditions. Trials in which the distractor was primed led to shorter times relative to trials in which the target was primed. This was true for both explicit and implicit trials. Conventions as in Figure 3.

the prime was the distractor object, the gaze was directed towards this object earlier than when the prime was the target object, other effects were not significant. Simple effects analysis investigating the effect of prime type in the different categories of conscious perception revealed that this effect was significant for both explicit and implicit trials [one tail paired *t*-test, $p < 0.001$; $p < 0.05$, explicit and implicit trials, respectively]. Note that trials with a primed target are on average shorter than trials with a primed distractor (i.e. the change-detection target is found earlier, see Figure 3). In spite of this, when the distractor is primed, the eyes are directed toward the distractor object *earlier* than when the target is primed (see Figure 6). These results further strengthen the hypothesis that implicit primes indeed influence gaze position, most likely through the deployment of attention to the primed object.

Finally, note that overall the time until fixation on the distractor object is substantially shorter than the time to target object (compare Figures 5 and 6). This seemingly paradoxical result stems from the fact that there is an inherent asymmetry between the two conditions: Change detection usually occurs following fixation on the target area. Therefore, while distractor fixation may precede target detection, only rarely do trials include fixation on the distractor object *after* fixation on target object (that did not result in recognition of the change target).

To make sure the priming effects found in Experiment 1 were not driven by a minority of the subjects, we examined how many subjects exhibited the implicit priming effect in each of our dependent measures. Importantly, analysis of the data, on a subject by subject basis, reveals that a substantial proportion of subjects show implicit priming effect in all measures (67% 67% and 70% for RT, time to target and time to distractor effects, respectively). We can therefore conclude that the present results are robust and are not driven by outliers.

Experiment 2

Priming can be fractionated into several different subtypes. One basic distinction is between perceptual priming and conceptual priming. Perceptual priming is modality specific and does not depend on elaborative semantic encoding of an item, whereas conceptual priming is not modality specific and benefits from semantic encoding (Blaxton, 1989). In order to investigate the influence of different prime types on the deployment of attention, we used a conceptual prime type—words—in this experiment. The design was identical to the first experiment, except for using words describing objects as primes rather than images of the objects.

In 13% of the trials, the subjects did not indicate detection of the change using the key response or failed to indicate the correct position of the change. These trials were discarded from further analysis. Using the forced choice task, trials were categorized to explicit (69.1 ± 10.8%) and implicit (30.9 ± 10.8%) trials.

Reaction time analysis

In Experiment I, when the subjects implicitly perceived the primes, they were faster to detect the change when the prime was of the target object (Figure 3). Interestingly, in Experiment II, no significant enhancement in response

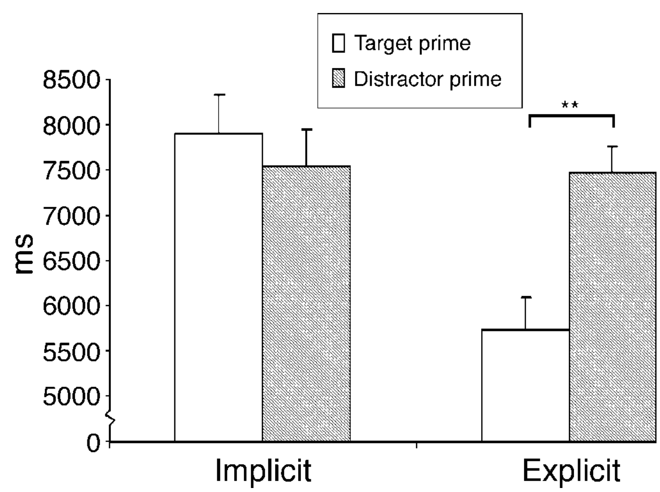

Figure 7. Average response time for successful change detection when using word primes. In explicit trials, response times were significantly shorter for trials in which the target was primed relative to trials in which the distractor was primed; For implicit trials, there was no significant difference between target and distractor primes. Conventions as in Figure 3.

time was observed for implicitly perceived word primes (Figure 7).

A two-factor repeated measures ANOVA was conducted across subjects on the average response time in the change detection task. The ANOVA revealed a significant main effect of prime type and perception type [$F(1, 26) = 6.7$, $p < 0.02$; $F(1, 26) = 9.9$, $p < 0.005$, respectively]. These effects can be fully accounted for by the significant interaction of the two effects [$F(1, 26) = 12.4$, $p < 0.002$]. Simple effects analysis revealed a significant effect only for explicit trials [one tail paired t-test, $p < 0.0001$] (Figure 7).

Eye movement analysis

This analysis was conducted in trials in which the change was detected and subjects fixated the changed region before the end of the trial (79.6% of the trials ± 9.7% standard deviation).

In Experiment I, when the subjects implicitly perceived the primes, they were faster to fixate the target object when the prime was consistent with it (Figure 5). Interestingly, in this experiment, no significant enhancement was observed for implicitly perceived word primes (Figure 8). A repeated measures ANOVA was conducted on the average time to first fixation on the target ROI. This analysis revealed a significant main effect of prime type and perception type [$F(1, 26) = 8.9$, $p < 0.007$; $F(1, 26) = 8.4$, $p < 0.008$, respectively], but again, these effects can be explained by the interaction of the two effects [$F(1, 26) = 4.3$, $p < 0.05$]. Simple effects of prime type were only significant for explicit trials [one tailed paired t-test, $p < 0.001$].

Analysis of the time until first fixation on the distractor ROI was conducted on trials in which the change was detected and subjects fixated the distractor ROI before the end of the trial (52.2% ± 8.0% standard deviation).

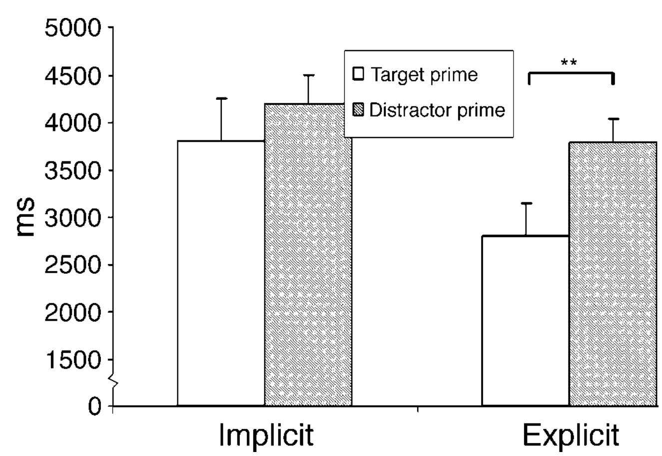

Figure 8. Time until fixation on target region—word primes. During explicit (but not implicit) trials, the time until fixation on the target ROI was significantly faster when the target was primed relative to trials in which the distractor was primed. Conventions as in Figure 3.

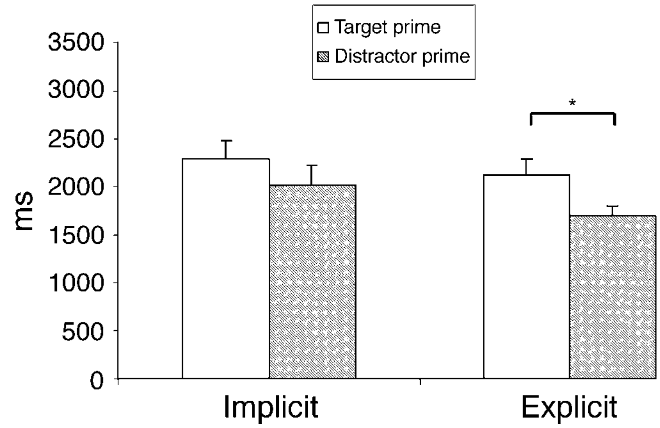

Figure 9. Time until fixation on distractor ROI—word primes. Analysis of the mean time until first fixation on the distractor ROI. During explicit (but not implicit) trials, the time to distractor ROI is significantly faster for trials in which the distractor was primed, relative to trials in which the target was primed. Conventions as in Figure 3.

Again, in contrast to the findings of Experiment I, in which implicitly perceived image primes of the distractor led subjects to fixate earlier on the primed object (Figure 6), implicitly perceived word primes did not elicit similar enhancement (Figure 9).

A repeated measures ANOVA on the averaged time it took the subjects' gaze to land on the distractor ROI revealed no significant effects, but there was a trend which indicated shorter time to ROI when the distractor is primed. Simple effects analysis of prime type was only significant for explicit trials [one tail paired t-test, $p < 0.05$].

Taken together, these results demonstrate that word primes which are perceived implicitly are clearly less effective than image primes. Implicitly perceived word primes do not appear to influence detection time, and seem to have only a subtle (but not statistically significant) influence on eye position.

Discussion

Summary

Subjects performed a classic change detection task following a brief presentation of a masked prime while we recorded their eye position. Primes could either be the images of a object (in Experiment I) or it's corresponding name (in Experiment II). In both experiments, the prime's identity was either the object to be detected as the changing object (target object) or a different object from the scene (distractor). As expected, when target primes (images or words) were explicitly perceived, change detection response time was facilitated and subjects' gaze was attracted more quickly towards the primed object. Critically, performance was similarly modified for *implicitly* perceived *image primes*, but not for implicitly perceived word primes. These results demonstrate that implicitly perceived image primes can direct subjects' gaze to their corresponding location.

Experimental task considerations

In the change detection task used here, subjects do not look for a specific predefined target but rather look for any change in the scene. The main advantage of this design is that it ensures that there is no explicit template of the sought-after target. Subjects are therefore more susceptible to experimental manipulations, such as our primes, which may activate such a template, even when only implicitly perceived. Another advantage is that we were able to follow gaze scanning patterns for relatively long durations without the subjects losing interest in the task. One disadvantage of this task is that it is somewhat unnatural, as the pictures abruptly appear and disappear (at approximately 2 Hz, see Supplementary materials for trial examples). It is yet unclear how this flicker affects subjects' scanning patterns; however, it is likely to affect the different experimental conditions in a similar fashion.

Given our experimental design, we could potentially categorize trials (i.e. implicit or explicit), based on either the first introspective task (as was done in previous studies) or according to the second forced choice task (performed after the change detection task at the end of each trial). We decided to use the forced choice method for two main reasons: first, this task is less prone to inter-subject differences in reporting threshold. Second, performance in trials in which subjects introspectively reported the prime as "unrecognized" (trials that would have been categorized as "implicit" based on the first introspection task) was in fact better-than-chance in the second forced-choice task (Figure S1). This indicates that although subjects fail to recognize the prime, some information about its identity is still accessible. Therefore, taking the first response as a criterion for implicit processing, leads to erroneous inclusion of explicit trials within the implicit trials. Thus, the use of the second forced choice task as the inclusion criterion leads to a "cleaner" sample of truly implicit trials. The disadvantage of using this approach is that implicit trials for which subjects correctly guessed the response are categorized as explicit. However, since the processing of the implicit trials is our main interest (rather than the explicit trials) we decided to use the forced choice reports. Note, however, that both methods yielded similar results in both experiments (see Figures S2 and S3 for Experiments 1 and 2, respectively).

Using the explicit trials, subjects could have potentially noticed that the prime often indicated the target object (in half the trials). The knowledge that the primes contain information on the changed object might have attracted special attention to the primes and enhanced their influence. Further experiments are needed in order to determine whether primes which are orthogonal to the viewing task (such as two different distractors appearing in the change detection scene) would also influence gaze control.

What guides the eyes?

Many other studies have investigated oculomotor guiding processes. These studies can be generally categorized to two main schools: According to one approach, fixation patterns are accounted for by the salience of the low level image properties (such as contrast, or movement; see Itti, 2005; Itti & Koch, 2000; Tatler, Baddeley, & Gilchrist, 2005). In contrast, a different set of studies showed that the eyes are positioned at a point that is not the most visually salient, but rather is best suited for the spatio-temporal demands of the task at hand (Hayhoe et al., 2003; Land, Mennie, & Rusted, 1999). This was the typical result in extended natural visuo-motor studies, testing oculomotor behavior during driving, walking, sports, and making tea or sandwiches. These studies demonstrated how explicit knowledge of the task controls the guiding mechanisms of the eyes: for example, when a cup is needed for making tea, the eyes locate it prior to the hand grasping movement. When encountering a new scene, several saliency-driven fixations are initially made, and as viewing proceeds, top-down control process takes a greater role in guiding gaze position (Mannan, Kennard, & Husain, 2009; Tatler et al., 2005).

Several models such as the "biased competition model" (Desimone, 1998) and "reentry hypothesis" (Hamker, 2003) describe possible mechanisms for the process of selecting the next target of fixation (or attention) according to high-level needs. These models propose that objects in the scene activate corresponding representations in the brain, which then compete for visual awareness and motor behavior. Competition among different representations is biased towards the element in the scene with the highest similarity to the goal object (target). Therefore, these models assume that some kind of a representation of the target (e.g. a template, which probably is maintained in working memory) is capable of guiding gaze/attention across space. The existence of such target template has supportive evidence from both psychophysical and electrophysiological studies. Conjunction search (Bichot & Schall, 1999a; Findlay, 1997; Williams, 1967) and search for "real" objects (Zelinski et al., abstract presented in VSS conference 2008) show higher incidence of saccades to distractors which are similar in shape to the target. Furthermore, the target features in the previous trial automatically affect the search template, by biasing erroneous saccades towards similar distractors (Kristjansson, Wang, & Nakayama, 2002). Single cell recordings in the frontal eye fields of non-human primates (Bichot & Schall, 1999b) during conjunction search task, reveal that the neural activity evoked by a distractor with a visual similarity to the target, is greater than for distractors that have no similarity to the target. This effect is retained in time, as a target in one session has its effect in the following session, even if the target identity is changed. From all the above studies, one can conclude that some kind of representation of the target could be activated implicitly and influence the oculomotor/attentional behavior across relatively long periods of time.

We suggest that, in our case, an implicitly perceived object, primes the attention process towards its corresponding location later in time, in a similar fashion to the way activated representations of previous targets affect attention (Kristjansson et al., 2002), or the way improvement in search performance is gained from seeing the actual target (rather than its description) prior to searching for it (Wolfe, Horowitz, Kennera, Hylea, & Vasan, 2004). In that way, activation of the visual template of the primed object enhances the saliency of that object.

Word primes

Previous experiments with word primes have demonstrated facilitatory effects in word naming (Ferrand, Grainger, & Segui, 1994; Sereno, 1991) as well as in lexical decisions (Segui & Grainger, 1990; Sereno, 1991). However, in contrast to implicit image primes, here an implicit word prime fails to attract the gaze to its corresponding object in the scene. This discrepancy could be explained by the fact that the other tasks (object naming and lexical decisions) rely on high-level processing while gaze control may rely on a low-level visual representation of the target object. Presumably, subthreshold word primes influence perceptual identification and naming but fail to access and activate such visual representations. In accordance with this view, it has been demonstrated that visual search is substantially more efficient when observers were shown a picture of the target (e.g., a black vertical bar) than when they were given a verbal description of the target (e.g., the phrase "black vertical bar") and this was also the case when real objects were used (Wolfe et al., 2004).

In an apparent disagreement with our results, one study did find evidence for enhanced performance in a change detection task when word primes were used (Walter & Dassonville, 2005). We speculate that the difference in the effects of word primes between our study and the one conducted by Walter and Dassonville might be due to the fact that their subjects were required to read aloud the words. Actively trying (and failing) to read may lead to more enhanced processing of the word than just watching them, even in implicit cases.

In contrast to their method, we used a visual forced-choice task to sort the trials into "implicit" and "explicit". Trials with incorrect responses were deemed as "implicit", while trials with correct responses were deemed as "explicit". On those trials in which the subject cannot consciously perceive the prime, he or she will guess correctly half of the time. Therefore these trials will be miss-categorized as explicit. This conservative inclusion criterion (for implicit trials) obviously leads to less statistical power, which theoretically may account for our failure to replicate Walter and Dassonville (2005). However, even when we reanalyzed our data, using the first introspection stage for categorizing the trials as in Walter and Dassonville (2005) and hence improving the statistical power, we were not able to find priming effects for words (see Figure S3). Moreover, in our study, which is focused on comparing the effects of image and word primes, there were actually more implicit trials using word primes (Experiment II) compared to image primes (Experiment I). Therefore Experiment II actually had a greater statistical power (in terms of number of implicit trial) than Experiment I. Thus, this comparison provides further evidence that the lack of implicit effect for word primes cannot be attributed to a problem of statistical power. Taken together, these additional analyses suggest that methodological differences in the experimental design (see above) rather than statistical power could be accounted for the different results obtained in the present study compared to the Walter and Dassonville (2005) study.

Another possible explanation for the lack of effect of the word primes relative to the image primes is the different proportions of implicit responses. In the word experiment there were more implicit responses (30.9% Vs 23.1% in the word vs. image experiment). This difference may potentially lead to the explanation that the image primes were on average closer to consciousness threshold to cause implicit effects while the word primes were not (see Walter & Dassonville, 2005 for a similar argument). This is a reasonable explanation, however, we do not find supportive evidence for that account in our results—as no correlation (on a subject wise basis) was found between the proportion of implicit reports and any of the implicit effects (see Table S1 in the Supplementary materials).

We therefore conclude that, when a strict criterion is used for determining implicit perception of primes, words are *less* capable of priming gaze towards the corresponding object, at least under the experimental conditions used here.

Concluding remarks

We find that an image of an object which is only implicitly perceived still yields better performance in a change detection task (shorter RT) and attracts gaze to the location of its corresponding object. Our findings suggest that a visual template matching process is continuously active even in the absence of explicit awareness. As such, it provides at least some explanation as to why we can constantly make eye movements without being explicitly aware of their exact destination. We propose that this mechanism enables locating behaviorally relevant objects during everyday life by activating relevant visual templates and directing our eyes to locations most similar to these templates. In our study, word primes did not seem to improve performance in the change detection task or orient gaze towards corresponding locations, thus implying that the gaze control mechanism is more tightly linked to concrete visual representations than to more abstract, semantic ones.

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