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BRIEF REPORT

Facilitatory priming of scene layout depends on experience with the scene

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Abstract Facilitatory scene priming is the positive effect of a scene prime on the immediately subsequent spatial processing of a related target, relative to control primes. In the present experiments, a large set of scenes were presented, each several times. The accuracy of a relational spatial-layout judgment was the main measure (which of two probes in a scene was closer?). The effect of scene primes on sensitivity was near zero for the first presentation of a scene; advantages for scene primes occurred only after two or three presentations. In addition, a bias effect emerged in reaction times for novel scenes. These results imply that facilitatory scene priming requires learning and is top-down in nature. Scene priming may require the consolidation of interscene relations in a memory representation.

Keywords Human visual perception · Spatial layout · Depth perception · Distance perception · Priming · Scene perception

When a familiar target scene is preceded by a same-scene prime, spatial judgments about the relations within the scene are faster than with control primes (e.g., Castelhano & Pollatsek, 2010; Gottesman, 2011; Sanocki, 2003; Sanocki & Epstein, 1997; Sanocki, Michelet, Sellers, & Reynolds, 2006). This effect is thought to occur because the scene prime activates a representation of the scene, which facilitates subsequent spatial processing within the scene. Results have indicated that scene priming is neither sensory in nature (e.g., Sanocki, 2003) nor highly abstract—it does not depend on either scene labels or knowledge (Sanocki, 2003; Sanocki et al., 2006). Instead, spatial relations are critical, both between objects and within the scene (Sanocki, 2003).

In the present experiments, I examined whether the priming effect depends on prior experience with the scene. Top-down explanations of scene priming emphasize higher-order representations that encode prior experience, including spatial interpretations. Because the representation is a product of experience, learning effects could occur. In particular, priming could be greater for familiar than for new scenes, because the familiar scenes have stronger preexisting representations. A role of familiarity in scene processing is suggested by contextual cueing, in which the speed of visual search gradually improves with experience with scenic displays (e.g., Brockmole, Castelhano, & Henderson, 2006). Prior work with scene priming, however, has not provided a sensitive test of the initial effects of experience with scenes (but see Castelhano & Pollatsek, 2010; Gottesman, 2011; Sanocki et al., 2006).

To examine whether scene priming develops with experience, the present experiments were conducted with a large set of natural scenes, repeated several times. Primes can increase the sensitivity of processing a target, but they can also cause bias effects (see, e.g., Neely, 1991; Ratcliff, McKoon, & Verwoerd, 1989; Sanocki & Oden, 1984). Because of this possibility, the first two experiments were designed to measure the accuracy of perceiving brief targets. Accuracy provided a fairly pure measure of sensitivity because brief presentations reduce the possibility of late-stage influences on target processing, such as decisional confidence. A bias influence in priming is illustrated with another measure in Experiment 3.

Experiment 1

To examine priming during the initial presentation of scenes, a total of 128 scenes were presented once during

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the first two blocks of trials, with 64 preceded by one type of prime (a matching scene prime or an uninformative control prime). Each scene was then repeated once during Blocks 3 and 4, with the same target but with the other prime. Each trial, involving a target and prime, was counted as one presentation of the scene. The targets contained two probes in the scene, and observers made a relational judgment indicating which probe (left or right) was closer to the given viewpoint (e.g., Fig. 1, right image).

During the first presentation of a scene, there was no opportunity for the scene prime to bias decisions, because each response was equally likely after the prime. When the scene targets were repeated in Blocks 3 and 4, however, memory for the earlier response to the target could influence processing.

The primes were presented for 400 ms, followed by a 100-ms mask and then the target. The prime duration seemed a reasonable initial setting, because 200 ms provides an optimal priming effect with familiar scenes (Sanocki & Sulman, 2009), and 500 ms is sufficient for fairly detailed interpretations of novel scenes to be encoded into memory (e.g., Fei-Fei, Iyer, Koch, & Perona, 2007).

Method

Participants The participants were students at the University of South Florida who volunteered for extra course credit. All of the participants reported normal or corrected-to-normal vision. The data from 22 students (15 female, seven male) were analyzed in Experiment 1; the data for an additional three were excluded from the analyses because of low performance, as will be explained.

Stimuli The 128 test scenes were selected from a larger set of color photographs of typical scenes (e.g., buildings, streets, and interiors). The photographs served as scene primes. One target was created for each photograph by superimposing two reddish ovals on the image, by changing hue in Adobe Photoshop (e.g., Fig. 1; see Sanocki, 2003). In half of the targets (and scenes), the left region was closer, and in half, the right region was closer. Some near probes were placed higher in the visual field than were far probes, in order to invalidate simple use of the depth cue of height in the visual field (e.g., Fig. 1). The control prime was a central rectangle, and a pattern derived from an unused scene was used as a mask (see Fig. 1).

Procedure The participants were run individually using a G4 Macintosh computer controlled by a custom RealBasic program. The stimuli were presented on a 17-in. CRT monitor in full color and were 550 × 367 pixels (20.2 × 12.3 deg of visual angle, at the 60-cm approximate viewing distance). The monitor refreshed every 11 ms.

Each trial began with a 500-ms gray cross (against white) that served as a fixation stimulus, followed by the prime for 400 ms, a 100-ms interval with the mask, the target for one of three durations, and then another 300 ms with the mask. The observer pressed a left or right key (“1” or “2” on the number pad), corresponding to the relative position of the closer probe. Observers were instructed to use the first picture in each sequence (scene or control prime) to “prepare for the red dots.”

There were four blocks of test trials, of 64 trials each. Each scene appeared once in Block 1 or 2 and once in Block 3 or 4, with the order of the prime types (control or scene first) randomly determined. Breaks were given every 16 test trials. The test portion of the experiment was preceded by six

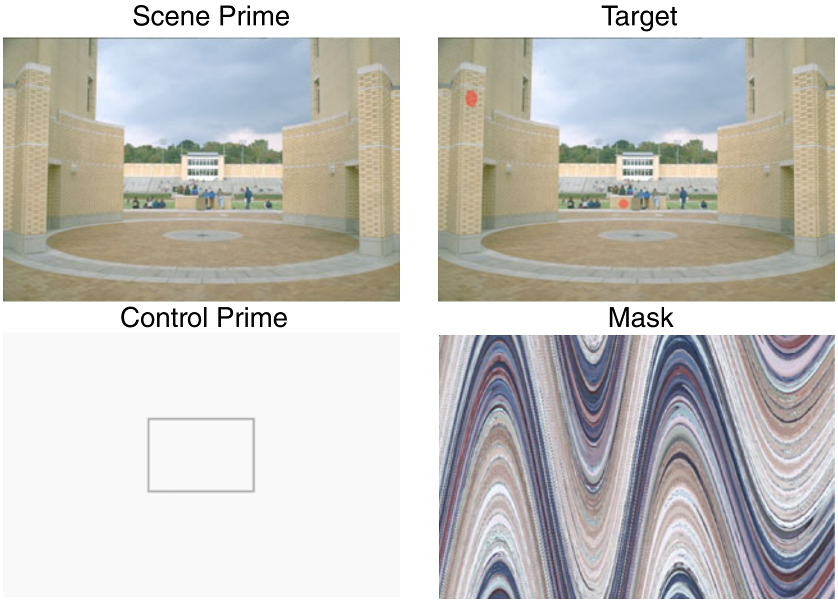

Fig. 1 Examples of the primes, target, and mask in Experiment 1

practice trials with scenes not used during testing as well as a long target duration (of 500 ms, to ease learning of the stimulus sequence).

Prime conditions and scenes were randomly ordered within each block. On test trials, the target duration was randomly selected from three values for each trial: a base duration (300 ms initially), base + 21 ms, and base + 42 ms. After every 16 trials, the base duration was adjusted in a staircase manner to maintain a level of accuracy near 75%. This kept the ease of seeing the target generally constant across the session and observers. Duration was balanced across prime conditions because trial order was randomized. The average duration at the end of the experiment was 201 ms (*SD* = 48 ms). The three target durations were used to explore processing-time effects; they produced main effects but no systematic interactions, and are not discussed further.

The data for participants were eliminated if their mean target durations were more than two standard deviations longer than the overall mean for the participants; on the basis of this criterion, the data of three participants were discarded.

Results

The main concern was the possibility of priming (advantage for scene over control primes) during the first presentation of the scenes (Blocks 1 and 2). No evidence of priming emerged; performance was as high when targets were preceded by control primes (79.6%) as when they were preceded by scene primes (79.7%), $F(1, 21) < 1$. The standard error of the priming effect across these two blocks was 1.5%.

Each scene (i.e., each target) was presented a second time during Blocks 3 and 4; Fig. 2 shows the priming effects across the two presentations (four blocks). In Blocks 3 and 4, a main effect of prime type can be seen, $F(1, 21) = 10.11$, $p < .01$, $\eta^2_p = .32$. However, the target probes and the response were the same as during the first presentation, and scene prime advantages could have been caused by prime-activated memory for the scene's probes or for the response.

Discussion

Experiment 1 was designed to examine priming during the first presentation of scenes, by contrasting performance for targets preceded by matching scene primes with that for targets preceded by the control prime. No advantage for scene primes was apparent during the first presentation of a scene. The measure of priming was fairly sensitive during these blocks, as indicated by the small standard error for the priming effect. There was a reliable priming effect when the scenes were repeated in Blocks 3 and 4, but the cause of this effect is ambiguous.

The results suggest that without prior experience, scene primes are not functional: They do not facilitate spatial processing within targets. Only after some experience with a scene does the scene prime become effective. Prime effectiveness may depend on a sufficiently strong memory representation that includes spatial relations, and this may be a product of experience with a scene. When the representation is reactivated by a scene prime, the activated spatial relations could increase the sensitivity of spatial processing within the scene. However, the priming effect obtained on the repeated presentations of this experiment could also have been caused by memory for the probes or the response. To rule out the effects of probe or response memory, in the next experiment the probes within each scene were varied.

Experiments 2A–2C

The purpose of Experiment 2 was to examine priming during the first several presentations of scenes. A total of

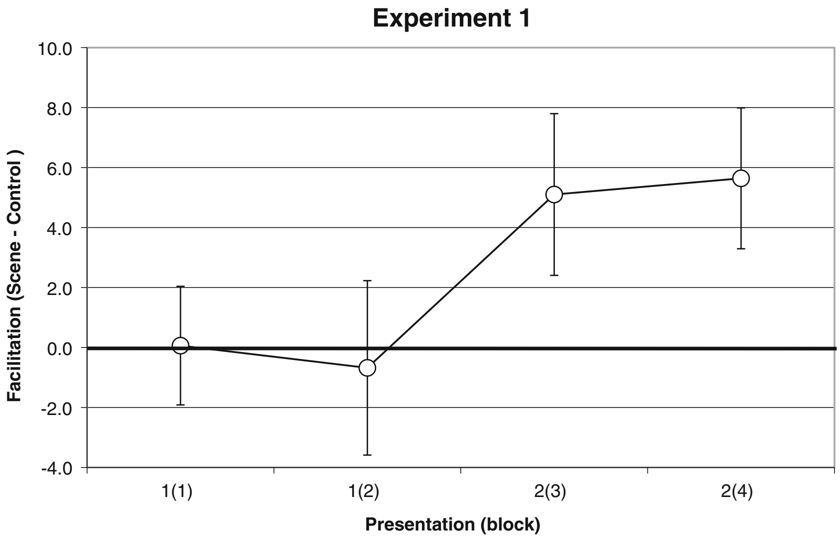

Fig. 2 Facilitation effects (scene prime – control prime) on accuracy in Experiment 1 for the two presentations during the four blocks. Facilitation was calculated in each block from the appropriate subset of scene-prime and control-prime scenes, and the bars indicate the standard errors of this effect within blocks

48 scenes were selected, and a second target with new probe relations was created (e.g., the bottom right image in Fig. 3). The response associated with a given scene, as well as the interpretation of individual probes (right closer versus left closer), varied from presentation to presentation. Priming was measured over the first four presentations of each scene, which corresponded to Blocks 1–4 in this experiment.

If a functional scene representation is created during experience, the duration of primes is potentially an important variable. The 400-ms duration of Experiment 1 may not have been long enough for a functional spatial representation of a novel scene to be created. In the present experiment, prime durations of 400 and 1,200 ms were chosen, with separate groups of participants. Also, to begin examining the importance of stimulus area in scene encoding, a third condition was run in which the relevant area of each scene was marked by a red frame, delimiting the possible probe locations in the target (e.g., Fig. 3, left column images). If the creation of a functional scene representation is limited by spatial area, priming should increase more rapidly in this condition than in the corresponding undelimited 1,200-ms group.

Method

For each of 48 scenes, a second target version was created with the opposite probe relation and response (see, e.g., Fig. 3). For 26 of the scenes, one probe was shared between the two targets, but with a different interpretation (i.e., close in one target, far in another). The remaining 22 pairs of targets had no common probes. The shared probes should discourage the use of individual probes in making the response. For the frame-delimited group, the red frames varied from scene to scene and designated an average of 35% of the scene area (57 × 62 pixels, *SD*s of 73 and 69 pixels). Each frame appeared in both the scene prime and in a control prime created for the scene and used (only) for this group.

The experiment consisted of four blocks of 48 trials each; each scene appeared once within each block, in one of the four stimulus conditions (defined by scene vs. control prime and by target version/response). Breaks were given every 24 trials, and target durations were then adjusted. Test trials were preceded by 24 practice trials with a set of six additional scenes, in which each practice scene appeared once in each of the four stimulus conditions.

The three prime groups were a 400-ms prime group with 28 participants (22 female, six male; Exp. 2A), a 1,200-ms prime group with 39 participants (33 female, six male; Exp. 2B), and a 1,200-ms delimited prime group with 26 subjects (24 female, two male; Exp. 2C). The average base target durations were, respectively, 172, 188, and 186 ms. As previously, the data for low-performing observers were discarded (six in total: three in Exp. 2A and three in Exp. 2B).

Results

An analysis of variance was conducted with the factors Prime Type, Prime Group, and Presentation (block). An overall priming effect emerged, $F(1, 90) = 9.88$, $p < .01$, $\eta_p^2 = .1$, but it varied with presentation, $F(3, 270) = 2.71$, $p = .04$, $\eta_p^2 = .29$, and this interaction tended to change with prime group, $F(6, 270) = 1.99$, $p = .07$, $\eta_p^2 = .007$. The results are shown in Fig. 4, with a solid line for the overall mean. To characterize priming within each group (dashed lines in the figure), *t* tests were used (all two-tailed). The overall reliability of priming for each presentation was then addressed in a combined analysis.

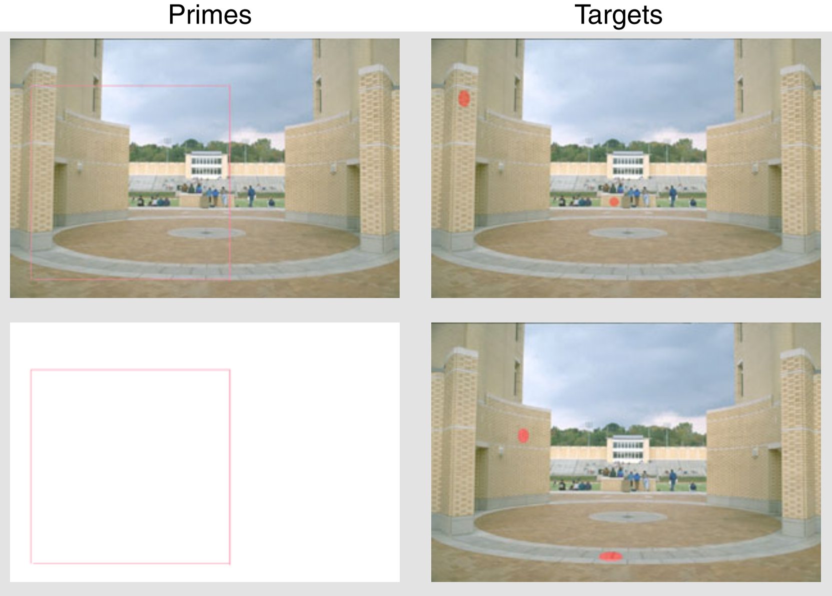

Fig. 3 Examples of primes in the 1,200-ms delimited group, as well as of targets for all groups, in Experiment 2

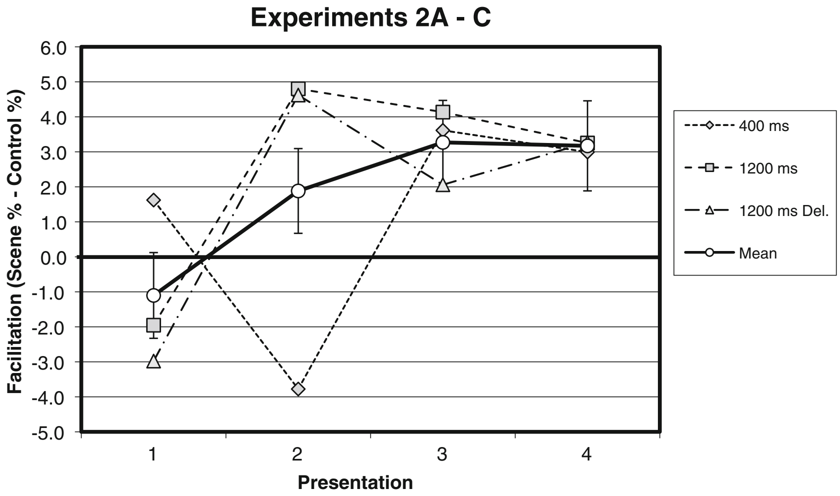

Fig. 4 Facilitation effects (scene prime – control prime) on accuracy in Experiment 2 for the four presentations. Standard error bars are shown for the combined data in each block

400-ms prime group (Exp. 2A) The group with the shortest prime durations showed no priming during the first presentation, $t(27) < 1$, and a marginal inhibitory effect during the second presentation (–3.8% effect), $t(27) = 1.96$, $p = .06$. A positive priming effect occurred during Presentations 3 and 4 combined, $t(27) = 2.5$, $p = .02$.

1,200-ms prime group (Exp. 2B) With a longer prime duration, still no priming occurred during the first presentation, $t(38) = 1.13$, $p > .20$. However, a reliable priming effect emerged both for the second presentation, $t(38) = 2.54$, $p = .02$, and for Presentations 3 and 4 combined, $t(38) = 2.39$, $p = .02$.

1,200-ms delimited prime group (Exp. 2C) With a longer prime duration and a delimited area in the scenes, the pattern was similar to that from the undelimited 1,200-ms group: no priming during the first presentation, $t(25) = –1.72$, $p = .10$, but reliable priming for the second presentation, $t(25) = 2.32$, $p = .03$, and for the last two presentations combined, $t(25) = 2.28$, $p = .03$.

Combined-groups analyses The pattern of positive and null priming effects was fairly systematic across prime groups and is summarized by the solid line in Fig. 4. No evidence of priming is apparent during the first presentation in any of the conditions, replicating Experiment 1, $F(1, 90) = 1.14$, $p > .20$, $\eta_p^2 = .012$. The second presentation appears to be a transition period; with the briefer prime duration there was no priming, whereas in both longer-duration groups the priming effects were reliable. Priming was reliable for Presentations 3 [$F(1, 90) = 6.30$, $p = .01$, $\eta_p^2 = .06$] and 4 [$F(1, 90) = 5.94$, $p = .02$, $\eta_p^2 = .06$]. Thus, scene primes were not functional upon their first presentation, but they did become functional upon their second or third presentation.

The two 1,200-ms groups differed in the presence of the spatially delimiting frame. Despite large differences in the relevant areas, the patterns of results were similar between the two groups (all *F*s involving group < 1; see Fig. 4). This suggests that the slowness with which scene primes became functional was not due to limitations in how much of the area of a scene could be encoded during a brief presentation.

Discussion

Scene priming was obtained after one or two presentations of a scene. These scene-priming effects cannot be explained by memory for the response or the probes, because these changed over presentations. As in Experiment 1, scene priming required at least one prior presentation. Facilitatory priming occurred after two presentations in the present 400-ms group, as compared with one in Experiment 1 (cf. Figs. 2 and 4). This may be related to the changing probe interpretations. Also note that the asymptotic levels of priming tended to be somewhat smaller here than in Experiment 1.

The duration of the scene prime had some effect on the development of priming; scene priming occurred on the second presentation in the 1,200-ms duration groups, and on the third presentation in the 400-ms group. However, the amount of relevant area in the scene prime, as manipulated by the delimiting frame in one of the 1,200-ms groups, did not influence the development of priming. This result implies that encoding of relevant relations from a scene prime is not limited by encoding demands from areas beyond the frame-delimited regions.

Experiment 3

An accuracy task was used in Experiments 1 and 2 because reaction times and long presentations can allow decisional bias effects with novel scenes. For Experiment 3, the reaction time method was used instead. The design paralleled that for the 1,200-ms undelimited prime group of Experiment 2.

Method

The stimulus sequence was the same as previously, with 1,200-ms primes. However, the target remained on the screen until the response. Auditory feedback ("correct" or "incorrect") was provided after each response (in contrast to the previous experiments). The data came from 42 participants (29 female, 13 male); an additional three data sets were discarded because of error rates above 10%.

Results and discussion

Response reaction times longer than 3 s were omitted from the analyses (0.7% of the data). The factors were Prime Type and Presentation. Most importantly, in the first block, priming exhibited a speed–accuracy trade-off: Error rates increased on scene-prime trials relative to control trials (Fig. 5, black symbols), while reaction times decreased (Fig. 5, white symbols). As can be seen, scene primes had a negative effect on accuracy for the first presentation, but the effect reduced to approximately zero by the third and fourth presentations. Accuracy was lower with scene primes across blocks, $F(1,\ 41) = 6.03$, $p = .02$, $\eta_p^2 = .13$, and increased over presentations, from 95.3% to 97.6%; $F(3,\ 123) = 6.35$, $p < .001$, $\eta_p^2 = .05$. The prime effect on accuracy tended to vary with presentations, $F(3,\ 123) = 2.26$, $p = .08$, $\eta_p^2 = .02$: The accuracy advantage for the control condition was reliable for the first presentation, $t(41) = –2.5$, $p = .02$, and marginal for the second, $t(41) = –1.9$, $p = .07$. Accuracy was similar for both prime types during the third and fourth presentations (ts < 1).

Overall, reaction times became faster over the four presentations—respectively, 1,029, 1,011, 971, and 950 ms, $F(3,\ 123) = 6.53$, $p < .001$, $\eta_p^2 = .05$. There was an overall advantage in time for the scene prime condition over the control condition, $F(1,\ 41) = 21.06$, $p < .001$, $\eta_p^2 = .34$. The interaction of prime type and presentation did not approach significance, $F(3,\ 123) < 1$. However, the scene-prime advantage did become larger and more reliable over exposures tested individually, becoming significant only for the third and fourth presentations [for the first, $t(41) = 1.23$, $p > .20$; second, $t(41) = 1.89$, $p = .07$; third, $t(41) = 2.88$, $p = .01$; and fourth, $t(41) = 3.70$, $p < .001$].

The accuracy differences imply that the somewhat faster reaction times with scene primes during initial presentations were due, at least in part, to observers trading speed for accuracy. For example, after seeing a scene prime, observers might be more confident when a same-scene target appears. This would cause observers to lower their decision criterion and to respond to the target more quickly but less accurately, as compared to control trials, when the target scene is entirely new (cf. Neely, 1991; Ratcliff et al., 1989). This effect occurred only during the first one or two presentations of the scenes. During the last two presentations, scene primes tended to produce slightly higher accuracy and faster responses—a genuine effect on sensitivity.

The conclusion that scene primes improved sensitivity only after two presentations converges with the results of Experiments 1 and 2. The speed–accuracy trade-off effect was restricted to the first two presentations of the novel scenes. This has implications for the study of scene priming: Novel scenes can cause additional but less interesting effects in reaction times, which disappear as scenes become familiar. These additional effects may involve relatively late effects in target processing, such as an increase in confidence caused by the scene prime. The effects did not occur with the accuracy task in Experiments 1 and 2, presumably because the brief presentations and accuracy measure did not allow for late influences on performance.

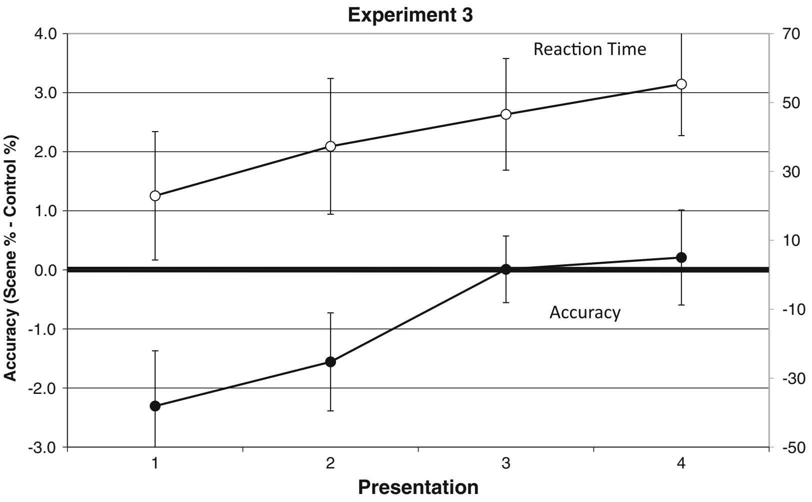

Fig. 5 Facilitation effects (scene prime – control prime) for accuracy (left axis) and reaction times (right axis) in Experiment 3. Standard error bars are shown for each presentation

General discussion

The present results indicate that the effectiveness of a scene prime depends on prior learning with the scene. Upon the first presentations of scenes, the overall scene-priming effect on the sensitivity of spatial processing was close to zero. Only after one or two trials with a scene did a positive scene-priming effect on sensitivity emerge. There was a bias effect for first presentations in Experiment 3, but no change in sensitivity.

Previous experiments have suggested that spatial-layout priming may occur with the first encounter of a scene (Castelhano & Pollatsek, 2010; Gottesman, 2011). However, those experiments measured reaction times primarily and were not designed to provide a powerful examination of first-presentation sensitivity effects. The Castelhano and Pollatsek experiments used a longer prime duration (2 s) and a study instruction that may have encouraged formation of a strong scene representation.

The present results also contrast with recent results demonstrating rapid processing of spatial-layout information (e.g., Gajewski, Philbeck, Pothier, & Chichka, 2010; Greene & Oliva, 2009). One important difference here is that the task depends on the spatial relations between locations within the scene, relations that vary from trial to trial. Spatial-relation processing may be relatively difficult, and sometimes sequential (e.g., Franconeri, Scimeca, Roth, Helseth, & Kahn, 2012). Spatial processing may be more rapid when the task depends on absolute distance information for one location (Gajewski et al., 2010) or on categorical spatial properties such as “openness” (Greene & Oliva, 2009). However, note that even rapid judgments improve with experience (Gajewski et al., 2010).

What specific processes improved with experience in the present experiments? Explanations in terms of scene encoding are mitigated by the finding in Experiment 2 that delimiting the relevant scene area had no influence. Perhaps a more likely locus of improvement is the ability to use the scene representation (memory) in a top-down manner. On each trial with a scene, the interpretation of the layout (including specific spatial relations) may be strengthened when a decision and response are made. A threshold level of interpretation strength may be necessary for priming to occur.

Prior results help to delimit the type of information that is critical for priming effects on sensitivity. As noted, scene priming is fairly abstract (Castelhano & Pollatsek, 2010; Gottesman, 2011; Sanocki, 2003; Sanocki & Epstein, 1997) and depends on the spatial relations between objects, and not just on the identity of the scene or objects (Sanocki, 2003; Sanocki et al., 2006). Scene priming does not appear to depend on either scene coherence or a scene’s global relations, because it occurs for upside-down scenes and piecemeal compositions (Sanocki et al., 2006). Scene priming may depend on major spatial relationships within probe-relevant regions of a scene, perhaps involving main objects and larger background surfaces. The present results suggest that these relations are processed into a useable form (a form that causes priming) only after one or more trials. Once sufficiently formed, relational memory units must be activated by a scene prime and target more quickly than bottom-up target processing activates such relations on control trials in order to cause a priming effect on spatial sensitivity. Longer scene-prime durations (1,200 vs. 400 ms in Exp. 2) appear to increase the likelihood of relational consolidation. Restricting visual area (delimited vs. undelimited primes in Exp. 2) was not helpful, possibly because only relations within the restricted area were relevant to the spatial judgment. In summary, scene priming appears to be a top-down effect, because it depends on spatial relations that have been consolidated into a functional (facilitatory) form.

Novel presentations of scenes are critical for studying the efficiency of bottom-up processing (e.g., Kirchner & Thorpe, 2006). However, the present results indicate that observers learn during repeated presentations of a scene. Given that observers often view a given scene in the real world for seconds or more, the effects of scene experience appear to be critical for understanding everyday scene perception.

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