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Implicit learning of ignored visual context

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Humans process a visual display more efficiently when they encounter it for a second time, showing learning of the display. This study tests whether implicit learning of complex visual contexts depends on attention. Subjects searched for a white target among black and white distractors. When the locations of the target and the attended set (white distractors) were repeated, search speed was enhanced, but when the locations of the target and the ignored set (black distractors) were repeated, search speed was unaffected. This suggests that the expression of learning depends on attention. However, during the transfer test, when the previously ignored set now was attended, it immediately facilitated performance. In contrast, when the previously attended set now was ignored, it no longer enhanced search speed. We conclude that the expression of visual implicit learning depends on attention but that latent learning of repeated information does not.

The role of attention in perception and memory is one of the longest standing debates in cognitive psychology. Extensive evidence suggests that perception and memory are attention dependent. For example, Rock and Gutman (1981) asked subjects to study a red outline shape overlaying a green outline shape and to rate how much they liked it. After many trials of aesthetic judgment, the subjects were given a surprise memory test in which they had to sort out the exposed shapes from novel ones. The subjects were able to recognize the shapes they had attended to, but not the ones they had ignored. In another study, Mack and Rock (1998) presented subjects with a cross shape, followed by a mask. The subjects were asked to judge whether the horizontal or the vertical segment of the cross was longer. After they had done this three times, something else, such as a dot, a word, or a shape, was presented near the cross. A substantial proportion of the subjects, when queried later, denied ever seeing the additional stimulus. These data suggest that attention is the gateway to perception and memory.

However, recent studies have shown that unattended objects often leave implicit traces that can be revealed indirectly. For example, using Rock and Gutman's (1998) stimuli, DeSchepper and Treisman (1996) found that ignored shapes produced a negative priming effect: Responses to the ignored shapes were slower when they later became targets. Using Mack and Rock's (1998) procedure, Moore and Egeth (1997) found that an unnoticed additional stimulus could affect perception of an attended stimulus. For example, when unexpected stimuli were arranged into arrowheads, they could produce the Müller-Lyer illusion. Consistent with such findings, Mack and Rock found that one's own name is often detected in the inattentional blindness procedure. They suggested that attention is not a gateway to perception and memory in general; it is only a gateway to conscious perception and explicit memory. Implicit processes are exempted from attentional limitations.

This study is concerned with the relationship between attention and implicit learning, an issue that has not been fully resolved. The role of attention has previously been studied primarily in the serial reaction time (SRT) task (Nissen & Bullemer, 1987). In this task, four positions are shown on the computer screen, each with a corresponding response key. An asterisk appears randomly in one location, and subjects press the corresponding key. Once they have pressed the key, the asterisk jumps to another location, and the subjects must press that key, and so on. Unknown to the subjects, the sequence of locations in which the asterisk appears follows a fixed 10-item sequence, such as BCADBCACBD. Many subjects do not notice the repetition, but their reaction times (RTs) are shorter for repeated than for novel sequences as the experiment progresses. When the SRT task is paired with a secondary tone-counting task, presumed to take away attentional resources, some studies have shown a reduction in learning (e.g., Nissen & Bullemer, 1987; Shanks & Channon, 2002), whereas others have not (e.g., Frensch, Wenke, & Rünger, 1999). A number of factors, individually or jointly, determine whether the SRT effect is affected by a secondary task. Sequences in which one loca-

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tion uniquely predicts the next is less sensitive to secondary tasks than other sequences are (Cohen, Ivry, & Keele, 1990). Secondary tasks produce a larger interference when they, too, have sequences of their own (Stadler, 1995). Finally, the tone-counting task appears to disrupt the expression of learning, but not learning itself, because when tested in single-task conditions, an SRT effect is revealed whether the earlier learning session involved single or dual tasks (Frensch, Lin, & Buchner, 1998; Frensch et al., 1999; but see Shanks & Channon, 2002). It suffices to say that implicit learning of a repeated sequence of perceptual–motor response is independent of attention under some, but not all, conditions. Unattended linguistic information can also be acquired incidentally (Saffran, Newport, Aslin, Tunick, & Barrueco, 1997).

A clear exception to the independence of implicit learning from attention is observed in the *contextual-cuing* task. Contextual cuing refers to a powerful and robust implicit visual-learning mechanism most often demonstrated in visual search tasks (Chun & Jiang, 1998, 2003). In tests of contextual cuing, subjects search for a T target among L distractors in many blocks of trials. The target is presented on every trial, surrounded by distractors that form a context for the target. The subjects are tested in two conditions, *old* and *new*. In the *old* condition, a given search display is presented in Block 1; it is repeated again in each block. The context (i.e., distractor layout) is thus consistently associated with a given target location. In the *new* condition, a target location is repeated across blocks, but the distractor locations are not. Thus, the target location is presented within a new context each time one sees it. Results show that RTs in the *old* condition start to diverge from those in the *new* condition after just five or six blocks, suggesting rapid learning of the visual context. In addition, the facilitation is retained for at least a week, showing long-term re-

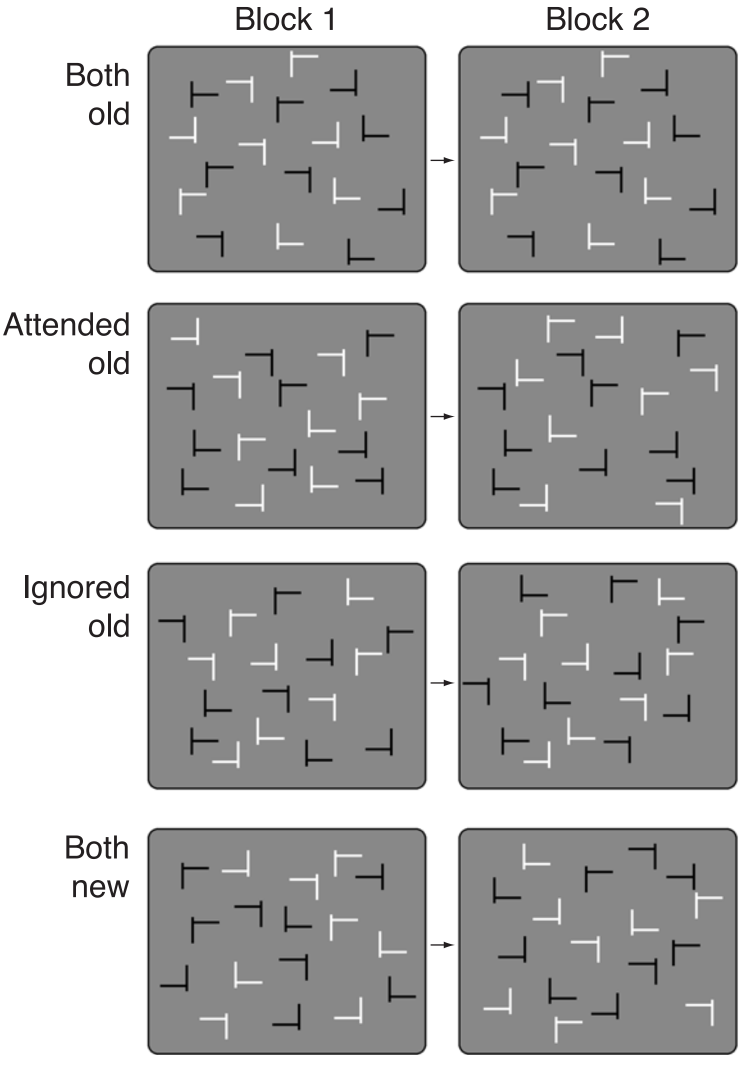

Figure 1. Sample search displays across two blocks. Subjects searched for a black T among black and white Ls and reported the orientation of the T.

tention (Chun & Jiang, 2003). Finally, contextual cuing is implicit. When asked to determine whether a given display is old or new, the subjects are unable to recognize the old displays (Chun & Jiang, 1998). Furthermore, if one replaces the target with a distractor and asks the subjects to guess which item was the target, the subjects are unable to make their guess at above-chance levels (Chun & Jiang, 2003).

Although cuing of attention by repeated context occurs implicitly, it is observed only when the repeated context is attended. In the standard contextual-cuing procedure, the context formed by distractors receives focal attention during the serial search process (Treisman & Gelade, 1980). If the search task involves a simple feature search, a repeated distractor context produces no advantage (Jiang & Leung, 2004, unpublished data). Furthermore, distractors that can be rejected quickly because they form a different perceptual grouping from the target do not produce contextual cuing (Jiang & Chun, 2001; Kawahara, 2003).

In this study, we reevaluate the role attention plays in contextual cuing. We distinguish between the expression of visual implicit learning, reflected by enhanced RT, and the learning itself. Although previous findings are consistent with the hypothesis of *attention-dependent learning*, they have convincingly shown only that the *expression* of visual implicit learning is attention dependent. Just because the ignored context does not enhance performance does not mean that it has not been learned. Studies on latent learning have taught us that the cognitive system can acquire knowledge without expressing it (Tolman, 1948). It is possible that when later attended, the previously ignored context may immediately facilitate performance. This alternative will be referred to as the *latent-learning* hypothesis.

To test whether latent learning of ignored contexts is possible, we adopted a procedure initially used by Jiang and Chun (2001). In this task, subjects search for a black target T among two kinds of distractors: black Ls and white Ls (for one half of the subjects, the colors were reversed). The black Ls formed the attended context, whereas the white Ls formed the ignored context. During 24 blocks of visual search, the attended set or the ignored set was repeated independently. This design allowed us to assess whether repeating the ignored context facilitates performance as much as repeating the attended context (Figure 1).

To dissociate the effects of attention on the expression of learning and on latent learning, we tested the subjects in a transfer session, during which the attended context and the ignored context switched colors. The target remained a black T, but the previously attended context (black Ls during learning) was now ignored (they turned into white Ls), while the previously ignored context was now attended (Figure 2). We can thus determine whether a previously learned context continues to facilitate performance when it is now ignored and whether a previously ignored context now facilitates performance when it is now attended. The hypothesis of attention-dependent learning predicts no advantage for the previously ignored context, whereas the latent learning hypothesis predicts an immediate benefit from a previously ignored context.

METHOD

Subjects

Twenty college students (18–24 years old) volunteered for this study.

Display

Each display contained one target and 16 distractors. The target was a white T for half of the subjects and a black T for the other half. The distractors were 8 black Ls and 8 white Ls. The subjects were told that their target would always be in white (or black) and that they should ignore the black (or white) distractors completely. The distractors that had the same color as the target formed the *attended set*; the other distractors formed the *ignored set*.

Each item subtended 1.1° × 1.1°. There was a small offset (approximately 0.1°) at the junction of the Ls to make search relatively difficult. Items were presented at randomly chosen locations within an invisible 10 × 10 grid (22° × 22°). The background was gray.

The subjects pressed a left key for a T pointing to the left or a right key for a T pointing to the right. They were asked to respond as accurately and as quickly as possible.

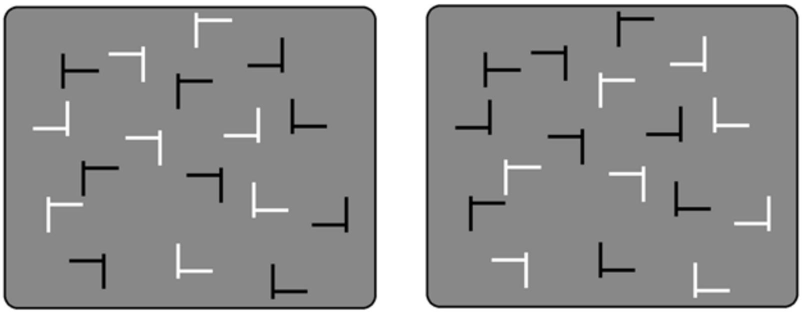

Figure 2. Relationship between training and transfer. Following 24 blocks of learning, subjects were tested in 2 blocks of transfer sessions, in which the two distractor sets switched colors.

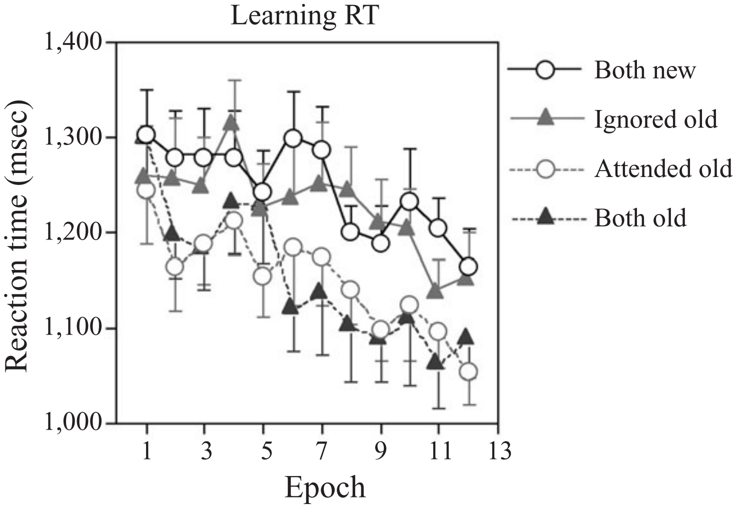

Figure 3. Results during the learning session: mean reaction time (RT) as a function of epoch (each epoch = two blocks) and context. *Both new*, locations of the target were repeated; *ignored old*, locations of the target and the ignored distractor set were repeated; *attended old*, locations of the target and the attended distractor set were repeated; *both old*, locations of the target, the attended distractor set, and the ignored distractor set all were repeated across blocks. Error bars show standard errors of the between-subjects variances.

Design

The subjects completed 26 blocks of trials; the first 24 blocks were the learning session, and the last 2 blocks were the transfer session.

Learning. Thirty-two trials were tested in each block, divided into four conditions: *attended old*, *ignored old*, *both old*, and *both new*. Each included eight trials. Each trial within a block had a unique target location, chosen randomly at the beginning of the experiment. These target locations were then repeated across blocks. Target eccentricity was balanced across the four conditions: If the target's location in one trial of an *attended old* condition was at [x, y], the target's location for the other three conditions would be [x, $-y$], [$-x$, y], and [$-x$, $-y$].

Each trial contained one target and 16 distractors, half assigned to the attended context and the other half to the ignored context. In all four conditions, a certain target location was always repeated across different blocks, but the distractor sets might not be repeated. In the *both old* condition, both the attended context (formed by distractors that shared the target's color) and the ignored context (formed by the other distractors) were repeated; in the *attended old* condition, only the locations of the attended set were repeated; in the *ignored old* condition, only the locations of the ignored set were repeated; and in the *both new* condition, neither context was repeated. The target's identity (left or right T) was randomly chosen on each trial.

Transfer. A transfer session started immediately after the last learning block, without any special instructions. Each block included 64 trials, half of which were the same as those in the learning session—that is, the colors of the attended and the ignored sets were maintained. These will be referred to as the *color stay* trials. The other trials were transfer trials, in which the previously attended and the ignored sets switched colors. These were the *color switch* trials (Figure 2). To eliminate the possibility of new learning of the color switch trials, only two blocks were tested. Color stay and color switch trials were randomly intermixed within a block; each included four conditions: *attended old*, *ignored old*, *both old*, and *both new*.

Trial Sequence

Each trial started with a fixation for 500 msec, followed by the search display, which was presented until a response was made. An incorrect response was followed by a beep. Then the display was erased for 500 msec before the next trial proceeded. At the end of each block, the subjects were allowed to take a short break and to continue at their own pace. They received about 150 trials of practice on totally random displays prior to the learning session.

RESULTS

Learning

Because of the small number of trials per condition per block, we averaged two blocks into one epoch. Mean accuracy ranged from 96% to 100% and was not significantly affected by any experimental factors (all ps $>$ .10). We calculated mean RT for correct trials in each subject. The individual subjects' mean RTs were then entered into an analysis of variance (ANOVA) and other statistical tests. Figure 3 shows the group mean.

The results clearly indicated that contextual cuing was determined entirely by the attended context: Repeating the attended set alone enhanced RT as much as repeating both sets did, whereas repeating the ignored set alone produced no facilitation (Figure 3). An ANOVA on epoch (1–12), attended context (repeated or novel), and ignored context (repeated or novel) showed a significant main effect of epoch [$F(11,209) = 6.09, p < .001$], with shorter RTs as the experiment progressed. There was also a significant main effect of attended context [$F(1,19) = 27.17, p < .0001$], with shorter RTs when the attended context was repeated, but no effect of ignored context [$F(1,19) < 1$, n.s.]. None of the interactions was significant (all *F*s < 1). Planned contrast showed that during Epoch 1, there was no effect of the attended context or the ignored context (*F*s < 1.10), suggesting that the baseline RTs were comparable across the four conditions initially. At Epoch 12, however, there was a significant main effect of the attended context [$F(1,19) = 12.19$, $p < .002$], but no effect of the ignored context and no interaction (*F*s < 1).

Thus, cuing of spatial attention to the target location was determined entirely by repetition of the attended context.

Transfer

Individual subjects' mean RTs in each transfer condition (Figure 4) were entered into an ANOVA and other statistical analyses. We first analyzed the color stay trials, which involved displays identical to the learned ones. An ANOVA on attended context and ignored context revealed a significant main effect of the attended context [$F(1,19) = 14.11$, $p < .001$], but no effect of the ignored context ($F < 1$, n.s.) and no interaction ($F < 1$).

Of particular interest are the color switch trials, in which the previously attended set became ignored and the previously ignored set became attended. An ANOVA showed no significant main effects of the previously attended [$F(1,19) = 1.61$, $p > .20$] or the ignored [$F(1,19) < 1$, n.s.] context, but there was a significant interaction [$F(1,19) = 6.05, p < .03$]. In particular, the previously ignored context, when now attended, led to a significant facilitation, as compared with the new condition [$t(19) = 2.60, p < .02$]. The previously attended context, now ignored, no longer facilitated performance ($t < 1$). Finally, the advantage for the *both old* condition was eliminated when the attended context and the ignored context switched color [$t(19) = 1.09$, $p > .25$], even though the overall configuration formed by all the items remained the same.

We contrasted the effect of color switching on the *attended old* and the *ignored old* conditions. An ANOVA on context (attended vs. ignored old) and transfer (color stay vs. color switch) revealed a significant interaction [$F(1,19) = 8.81, p < .008$]. This confirmed that whereas a previously ignored set, now attended, facilitated performance, a previously attended set, now ignored, no longer affected RT.

Because the transfer epoch included two blocks, new learning of the color switch trials was absent in Block 1 but was possible in Block 2. To ensure that the significant transfer of the previously ignored context was not due to new learning, we separated the data from the two blocks and conducted an ANOVA on block (first vs. second), attended context, and ignored context. The main effect of block was not significant ($F < 1$), and none of the interactions involving block was significant (all *p*s $> .16$). In the first transfer block, the previously ignored context produced a gain of 150 msec, as compared with the *both new* condition [$t(19) = 4.20$, $p < .001$]. This confirms that transfer of the ignored context was immediate.

DISCUSSION

Contextual cuing is a powerful implicit visual-learning mechanism. When a complex visual search display is repeated a few times, people can use the repeated context to guide attention to the position of the target. Learning and memory revealed by contextual cuing can be contrasted with the severe limitations in visual attention and working memory. Recent studies on change detection suggest that very few visual objects (about four) can be

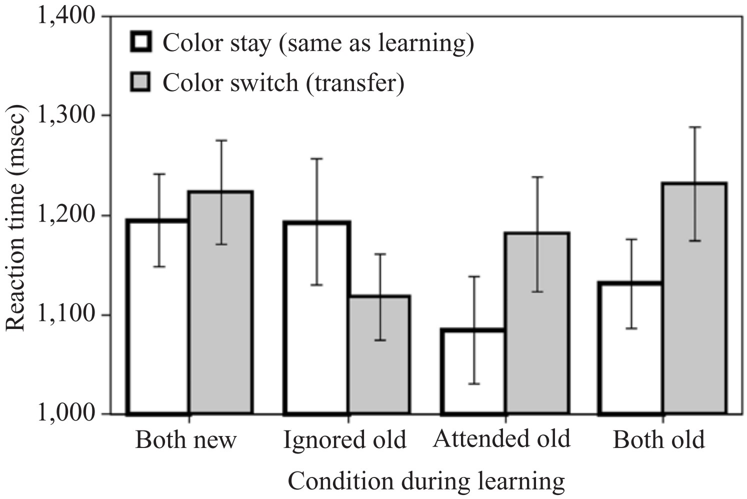

Figure 4. Results from the transfer epoch (the last two blocks). *Color stay* trials were the control condition, in which displays that were the same as the learning session were used. *Color switch* trials were the transfer condition, in which the previously attended and the ignored sets switched colors. Error bars show standard errors of the between-subjects variances.

maintained in working memory (Luck & Vogel, 1997) and that the human visual system is stunningly poor at representing visual details (Levin & Simons, 1997; Rensink, O'Regan, & Clark, 1997). Yet in contextual cuing, subjects are able to discriminate a few repeated displays from more than 300 new displays, none of which is particularly distinctive from the old displays. Because learning is fast, lasts for at least a week, and does not rely on awareness, it is an important mechanism that complements our severe limitations in working memory.

Our study has clearly demonstrated that whereas the expression of learning depends on our attending to the context, learning of the context itself is independent of attention. This finding is consistent with the latent-learning hypothesis. The expression of learning depends on attention because a previously learned context, now ignored, does not facilitate visual search. But ignored repetitions can be learned, because a previously ignored context, now attended, immediately leads to a cuing effect. These data are inconsistent with the idea that learning itself depends on attention.

Latent learning of ignored information is not always automatic, however. Consider the *both old* condition. It initially produced significant learning, driven by the repetition of the attended context. After color switching, the previously attended context no longer enhanced performance, and neither did the previously ignored context, which was now attended. Thus, when the ignored context was the only information predictive of the target, latent learning was possible; however, when the attended context, as well as the ignored context, was repeated, latent learning of the ignored context was not observed. This finding conforms to an effect of *associative blocking* in learning (Kamin, 1969), in which the association between a salient cue and the target blocks the association between a less salient cue and the target. Thus, even though latent learning for the ignored context is possible when it is the only repeated information, such learning may be blocked by more salient cues, such as the repetition of the attended context.

A recent study by Endo and Takeda (2004) provided direct evidence for the presence of associative blocking in contextual cuing. These authors presented subjects with multiple learning cues. For example, the distractor locations were predictive of the target's location, and the distractor shapes were predictive of the target's shape. They found that under such conditions, subjects failed to learn the association between distractor shapes and target shape, even though shape association was learned when it was the only cue in the experiment.

Associative blocking is separable from attention, because the subjects in Endo and Takeda's (2004) study were attending to both shape and location, yet only location association was learned. In our study, associative learning did not just affect what was expressed; it directly changed what was learned. This is different from the effect of attention: Attention affects what is expressed, provided that learning was not blocked in the first place. In short, if attention has any influence on latent learning itself, it is through associative blocking.

Latent learning of ignored contexts further demonstrates the power of contextual cuing. It suggests that the visual system may be able to track ignored information and compute the invariance. When humans are attending to other information, their behavior is dominated by the attended information; ignored contexts, even though potentially beneficial, are not used unless they later become attended. Behavioral relevance changes which portion of the display is attended. Disregarding ignored contexts is perhaps advantageous, because this allows one to focus more effectively on the attended information, ensuring that behavior is dictated by task-relevant information (Allport, 1989). A system that reacts to irrelevant, as well as to relevant, information would never achieve coherent behavior, as is the case with frontal lobe patients. These patients lack the ability to focus on task-relevant information; their actions are often captured by distractors. By focusing on relevant information, attention protects us from overtly reacting to irrelevant information. Yet the visual system manages to retain an ignored context for future use, maximizing its efficiency.

In conclusion, we have found that the expression of contextual cuing depends on the repeated context's being attended. An ignored context does not facilitate performance, consistent with previous findings. However, when the ignored context then becomes attended, it immediately facilitates performance, suggesting that latent learning has occurred. This finding is consistent with the idea that attentional selection occurs at a *late* stage (Deutsch & Deutsch, 1963). Unattended information is not filtered out early on; instead, it becomes represented in long-term memory. We conclude that the visual system is capable of learning from a repeated context independently of whether it is attended or ignored but that such learning is expressed only when the repeated context becomes attended. Our study reinforces the importance of separating the expression of learning from learning itself (Frensch et al., 1998; Frensch et al., 1999). It also supports the idea that implicit processes can escape the limits of attention.

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