VISUAL COGNITION, 2007, 15 (3), 257–275

Psychology Press
Taylor & Francis Group

Contextual cueing based on specific and categorical properties of the environment

Annabelle Goujon
CNRS & Université de Provence, Marseille, France, and INRETS, France

André Didierjean
Université de Franche-Comté, Besançon, France

Evelyne Marmèche
CNRS & Université de Provence, Marseille, France

During the analysis of a visual scene, top-down processing is constantly directing the subject's attention to the zones of interest in the scene. The contextual cueing paradigm developed by Chun and Jiang (1998) shows how contextual regularities can facilitate the search for a particular element via implicit learning mechanisms. The study presented here reports three experiments that used this paradigm. Experiment 1 showed that regularities in the specific elements of the context can act as cues to the location of the target. Experiments 2 and 3 explored a novel aspect of contextual regularities, namely semantic regularities based on the categorization of contextual elements. Contextual cueing effects were obtained when semantic-category membership of the context predicted the target location. Moreover, in all three experiments, contextual cueing effects were obtained implicitly. The results suggest that in target-detection tasks, implicit learning can be based not only on the specific constituents of the context, but also on the semantic categories of those constituents, depending on their predictive power.

During the analysis of a visual scene, the cognitive system quickly picks out the aspects of the scene most likely to lead to adapted behaviour. However, as a number of studies on change detection (e.g., Levin & Simons, 1997; for a review, see Rensink, 2002) and visual short-term memory (Irwin & Andrews, 1996; Luck & Vogel, 1997) have shown, only a minute amount of information can be accessed consciously and remains in working memory at a given instant. A question that arises concerns how the observer's

Please address all correspondence to Annabelle Goujon, LPC-CNRS & Université de Provence, Case 66, 3, place Victor Hugo, 13003 Marseille, France.
E-mail: goujon@up.univ-aix.fr

http://www.psypress.com/viscog DOI: 10.1080/13506280600677744

attention is directed toward the areas of interest in a scene, according to his/her current goal. The present study was conducted to approach this issue. The contextual cueing paradigm (Chun & Jiang, 1998) was used in order to investigate how implicit learning of regularities generated either by specific elements or by more general semantic categories in the context can facilitate visual-scene analysis.

During scene analysis, perceptual behaviours are largely guided by the interaction between bottom-up perceptual information taken from the image and prior knowledge of that kind of scene stored in long-term memory (for reviews, see Chun & Wolfe, 2001; Itti, 2003). Perceptual data derived from an image or scene is thought to activate an internal representation of the scene that directs the observer's attention to a given area within it (Rensink, 2000). Internal representations of scenes are thought to be based on perceptual *scene schemas*. In this view, the representation of a scene stored in long-term memory (LTM) contains an inventory of all objects likely to be present in the scene, along with their positions relative to each other (Mandler & Parker, 1976; Mandler & Ritchey, 1977). Indeed, although the visual world is composed of a multitude of details, it is nonetheless predictable: Objects in the environment are seldom arranged at random and events generally do not occur in an arbitrary order. On the contrary, the visual world is highly structured, in such a way that objects and events tend to covary in space, time, or both. For example, an office usually includes books, articles, pens, a computer, but rarely a road sign. The presence of such contextual regularities makes the visual world stable and predictable (Biederman, 1972; Palmer, 1975). Scene backgrounds are thought to be activated very early in the perception process, not only to influence stimulus perception and facilitate object identification (Biederman, Mezzanotte, & Rabinowitz, 1982; Boyce & Pollatsek, 1992; Boyce, Pollatsek, & Rayner, 1989) but also to guide scene exploration (Friedman, 1979; Henderson, Weeks, & Hollingworth, 1999; Shinoda, Hayhoe, & Shrivastava, 2001). The efficiency of our perceptual behaviours would thus tend to be contingent upon the existence of meaningful structured contexts (Gibson, 1969). Because knowledge of contextual regularities organizes visual scenes, it helps observers interpret the world and produce adapted behaviours, at the same time as it speeds up visual processing by directing attention toward the relevant aspects of the scene.

It remains to be determined what types of contextual regularities are detected by observers and how knowledge of those regularities is acquired and used, whether explicitly or implicitly. Contextual regularities may be related to the specificity of the context's constituents or their spatial arrangement; they may also concern the more or less predetermined chronology of a sequence of events; or still again, they may pertain to the overall meaning of the context, in which case they involve mechanisms that precategorize the elements that make up the context. In *contextual facilitation models* of object perception in scenes (Hollingworth & Henderson, 1998), the overall meaning of the context plays a greater role in context effects than the perceptual properties of contextual elements (Gordon, 2004; for a review, see Henderson & Hollingworth, 1999) or than the specific objects present in the scene (Boyce et al., 1989). However, while it is well-established that the general properties of the context affect perception, we still do not know how such knowledge is acquired. A question that arises in this framework is whether the semantic regularities inherent in certain categorical contexts can be learned and used implicitly, as specific regularities can (Chua & Chun, 2003), and, if so, whether implicit learning contributes to the construction of *scene schemas*.

To answer these questions, the present study used the *contextual cueing* paradigm developed by Chun and Jiang (1998), in an attempt to experimentally reproduce contextual-regularity learning effects. This paradigm is a variant of the classic visual search task (Schneider & Shiffrin, 1977; Treisman & Gelade, 1980). Subjects were tested on several blocks of trials. Half of the trials in each block were "predictive" and the other half were "nonpredictive". In the predictive trials, the target was always associated with a context that predicted its location or identity. In the nonpredictive trials, the target context was random. A contextual cueing effect would be manifested by faster and faster detection of targets presented on predictive trials than of targets presented on nonpredictive trials. This effect reflects contextual-regularity learning, and more specifically, the learning of context–target associations. Context–target associative learning is thought to facilitate visual searching by directing attention toward the target (Chun & Jiang, 1998; Peterson & Kramer, 2001). Contextual cueing tasks have also demonstrated another aspect of learning, its implicit nature (for reviews on implicit learning, see Cleeremans, Destrebecqz, & Boyer, 1998; Schacter, 1987), which is reflected by the fact that subjects rarely if ever report having noticed contextual regularities, yet contextual cueing effects are still observed. Another way of demonstrating the implicitness of this type of learning is to have subjects perform a recognition task immediately after the search task: participants are generally incapable of differentiating between predictive and nonpredictive trials (see Chun & Jiang, 1998, 2003).

Past research on contextual cueing has dealt with three aspects of the context, as defined by its constituents: Their spatial layout, their dynamic relationships, and their specific shape. Some studies have shown that the spatial layout of contextual elements can act as a cue to the location of a target in a static environment (Chua & Chun, 2003; Chun & Jiang, 1998; Olson & Chun, 2002), even when the predictive contextual elements were ignored during the learning or encoding stage (Jiang & Leung, 2005). Contextual cueing effects have also been observed in cases of temporal regularities, as in dynamic environments composed of items moving along predictable trajectories (Chun & Jiang, 1999) or when visual events take place in a predictable order (Olson & Chun, 2001). However, to our knowledge, there are only two studies (Chun & Jiang, 1999; Endo & Takeda, 2004) that have looked at contextual cueing effects brought about by a contextual-element specificity (here their shape). In the Chun and Jiang (1999) experiment, participants had to detect a target that was defined as the only shape in the display that was symmetrical with respect to the vertical axis. The shapes of the distractors in the display predicted the shape of the target. The results showed that the target's shape could in fact be cued by the specific shapes of distractor elements that covaried with it. Endo and Takeda (2004) extended these results showing that the specific shapes of contextual elements could cue the target location as well.

In the present study, we attempted to obtain classic contextual cueing effects based on specific contextual elements, independently of their spatial layout. But we also addressed a new kind of contextual regularity, namely, semantic regularities based on the categorization of the elements that make up the context. Can contextual cueing effects be extended to predictive contexts defined in terms of the semantic-category membership of their constituents rather than in terms of their specificity? If such contextual cueing effects are obtained, then we need to determine whether implicit learning took place, or whether the learning involved a semantic-property-based categorization process that was necessarily associated with awareness of the semantic-category regularities. Indeed, in a study using the contextual cueing paradigm with real-world scenes, Brockmole and Henderson (2006) have shown that semantic memory for scene–target covariation was explicit.

OVERVIEW OF THE EXPERIMENTS

Three experiments were conducted. The first was aimed at reproducing contextual cueing effects based on specific contextual elements; the second and third experiments investigated whether contextual cueing effects could be obtained from semantic-category properties. In all experiments, contextual cueing tasks with numerical displays were used. In Experiment 1, it was the specific numbers in the context that predicted the location of the target. For example, the context containing the numbers 11 and 57 predicted a particular target location. In Experiments 2 and 3, it was a categorical property, the evenness/oddness of the numbers in the context, that predicted the area where the target would occur. When the context was composed solely of even numbers, the target was located in a particular area of the display, and when the context was composed solely of odd numbers, the target was located in the opposite area.

EXPERIMENT 1

This experiment was designed to determine whether contextual cueing effects could be obtained from specific associations between a particular numerical context (made up of a pair of numbers repeated eight times) and the location of a particular target (13 or 28). It was based on the same principle as in the Endo and Takeda (2004) study, but differed by the fact that all the contexts, predictive and nonpredictive, were repeated across the experiment.

The experiment had two phases: A search task, followed by a verbalization-then-recognition task. In the search task, the subjects had to detect the target (13 or 28) in a context consisting of 16 numbers (a pair of numbers repeated eight times and randomly distributed throughout the display). Blocks of trials were presented. Each block was composed of "predictive" trials in which the specificity of the context predicted the target location, and "nonpredictive" trials in which the specificity of the context did not predict the target location. Figure 1 shows two examples of predictive trials in which the context (the pair 11–57 repeated eight times) predicted the location of the target (13 or 28). The hypothesis tested was that if the specificity of the numerical context can act as a cue to target location, then the detection time of a target presented in a predictive context should be shorter than the detection time of a target presented in a nonpredictive context.

A verbalization-then-recognition task was used to assess the explicitness versus implicitness of the knowledge acquired during the search task (Chun & Jiang, 1998).

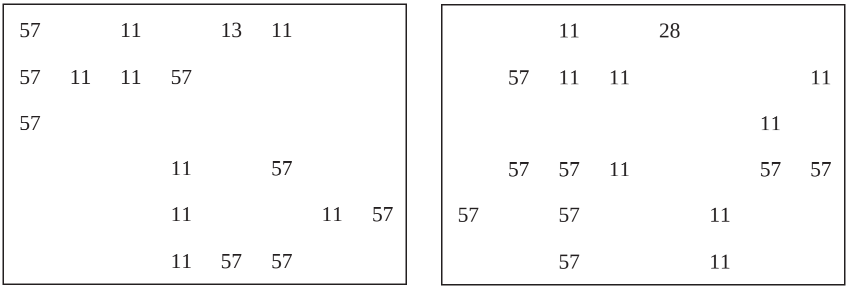

Figure 1. Example of two predictive trials. Predictive trials associated a particular numbers pair (here, 11 and 57) to a target location (the location of the target 13 or 28). The spatial arrangement of the contextual numbers was random. These two predictive trials (for this particular association) were presented in different blocks.

Method

Participants

Twenty-two students from the University of Aix-en-Provence, France, participated in the experiment (12 women and 10 men, mean age 23). All participants had normal or corrected-to-normal vision, and none were aware of the purpose of the study.

Apparatus

The experiment was implemented in PsyScope software and run on a portable Macintosh computer with a 15-inch screen. The subjects were seated approximately 50 cm from the screen. The stimuli (font size 24) were displayed on the screen in an invisible eight-column six-row grid. This made 48 possible item locations. The grid subtended 28 cm horizontally and 18 cm vertically.

Stimuli

Targets. Each trial had only one target, which was one of two numbers, 13 or 28. For the digit in the ones place, 3 and 8 were used because one is odd and the other is even, and because they resemble each other visually. The target 13 or 28 could appear in eight different locations on the invisible 8×6 grid.

Contexts. Each search area contained 16 context numbers, i.e., a pair of numbers repeated eight times. The numbers were two-digit numbers that were not the same as either target. Neither their tens digit nor their ones digit was 3 or 8. On each trial, the 16 context numbers were distributed randomly in the invisible 8×6 grid. The 17 items (16 context numbers and the target) were displayed in black on a white background.

There were two kinds of trials in the experiment, predictive trials and nonpredictive trials. In a predictive trial, a specific context was associated to a particular target location. In a nonpredictive trial, a specific context was not associated to a particular target location. The target location varied across blocks. In the nonpredictive trials, target locations were the same as those used in the predictive trials, which allowed us to compare predictive and nonpredictive trials, which differed only by the predictiveness of their context. For half of the subjects, the eight context pairs used for the predictive trials were 11–57, 69–74, 55–70, 47–52, 22–26, 40–77, 45–54, and 14–66; for the nonpredictive trials, the eight pairs were 42–62, 56–65, 10–25, 21–50, 71–75, 29–49, 20–44, and 16–61. For the other half of the subjects, the design was reversed.

Procedure

The experiment lasted about 30 min and had two phases, a search task and a verbalization-then-recognition task.

Search task. The subjects were instructed to detect the target on the screen as quickly as possible. They were told that on each trial, one target would be present, 13 or 28. Responding was done by pressing the key on the keyboard that corresponded to the detected target. The side (left/right) of the response key assigned to each target was counterbalanced across subjects.

The search task consisted of 24 blocks of 16 trials, making 384 trials in all. Each block was composed of eight predictive trials and eight nonpredictive trials, presented in random order. For each predictive trial, the association of a particular context (e.g., the context formed by the numbers 11 and 57) with a particular target location (e.g., the target 13 or 28 in a particular location, see Figure 1) was repeated in all blocks of trials.

The experiment began with the instructions. Then a practice block composed of eight trials was run in order to familiarize the participants with the experimental procedure. The practice trials used context pairs that were different from those used in the actual search task. Immediately after that, the participants performed the search task composed of 24 blocks of 16 trials. Within a given block, the 16 trials were presented randomly. The participants pressed a key to start the first block. After a 500-ms delay, a stimulus pattern appeared on the screen. The participants had to look for the target, and as soon as they found it, to press the corresponding key as quickly as possible. The subject's response immediately triggered the one-second display of a white screen with a black fixation point in the middle, after which the computer initiated the next trial. A break was programmed at the end of each block. Subjects could go on to the next block or extend the break as they pleased.

Verbalization-then-recognition task. After the search task, the subjects were asked two questions orally: "Did you notice any regularities in the material?" and "Did you notice that certain numerical target contexts were repeated during the experiment?" If the participants answered that they had not noticed any predictive repeated numbers or contexts, they were given the recognition task proper. Note that the subjects had not been told in advance that they would have to perform a recognition task. The recognition task consisted of a new block of 32 trials, 16 of which were generated in the same way as in the search task, i.e., 8 were predictive and 8 were nonpredictive. There were also eight "counterpredictive" trials and eight "nonpredictive filler" trials. In the counterpredictive trials, the target was located in a very different place than in the search task. The eight nonpredictive filler trials were added simply to balance the number of predictive and nonpredictive contexts in the recognition task. The subjects were instructed to look at the screen on each of the 32 trials and answer the following questions: "Do you have a feeling of 'déjà vu'?" "Does the association between the target location and the context numbers look familiar with respect to the search phase?" No time limit was set for answering.

Results

Search task. The error rate was below 1.6% for both the predictive and the nonpredictive trials, so the errors will not be discussed. Our analyses thus dealt solely with reaction time (RT) on correct answers. RTs above the mean plus three standard deviations were discarded from the analyses. This procedure eliminated about 1.2% of the correct-answer RTs. The correct-answer RTs were grouped into six epochs, each covering four consecutive blocks of trials. For each subject, a separate correct-answer RT mean was calculated for each epoch and each condition tested.

A repeated-measures ANOVA was conducted with condition (predictive vs. nonpredictive contexts) and epoch (1–6) as within-subject factors. The mean RTs for each condition and epoch are presented in Figure 2. The main result was a facilitating effect of predictive contexts on target-detection time.

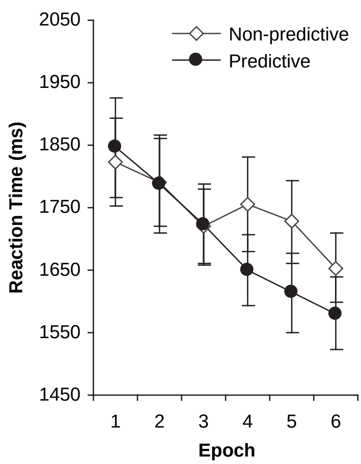

Figure 2. Mean target-detection reaction time in the nonpredictive and predictive conditions of Experiment 1, by epoch. The error bars represent the *SEM* ($N = 22$).

The ANOVA yielded a condition effect, $F(1, 21) = 5.986$, $p < .05$, an epoch effect, $F(5, 105) = 11.099$, $p < .001$, and a Condition × Epoch interaction, $F(5, 105) = 2.887$, $p < .05$.

Verbalization-then-recognition task. None of the subjects said they had noticed any predictive repeated contexts or numbers during the experiment, so they were all given the recognition task. The percentages of "familiar" answers were analysed. A repeated-measures ANOVA indicated no significant difference in the percentages of "familiar" answers between the predictive (52%), nonpredictive (52%), and counterpredictive conditions (47%), $F(2, 42) < 1$.

Discussion

The aim of this experiment was to extend contextual cueing effects to numerical material in a situation where the manipulated regularity was the specificity of the context, independently of its spatial layout. The results indicated that contextual cueing effects could indeed be obtained from predictable associations between certain numerical contexts and a particular target location. Chun and Jiang (1998) showed that the spatial layout of a context could serve as a cue to target location, and that the specific shape of the elements in the contextual environment could serve as cues to target's shape (Chun & Jiang, 1999). As in Endo and Takeda (2004) study, our results showed that the specificity of numerical contexts could act as a cue to target location. However, in our experiment all the contexts were equally repeated across the search task, and differed only by their predictiveness. Thus, the contextual cueing effects were indeed the result of an associative learning between specific context and target location. Moreover, the recognition-task results demonstrated the unconscious nature of the learning that took place. After 24 blocks of trials, none of the subjects reported having noticed any kind of regularity in the numerical contexts used in the search task. Moreover, the participants were not able to differentiate predictive from nonpredictive or counterpredictive trials on the recognition task.

Experiments 2 and 3 were aimed at finding out whether contextual cueing effects can also be observed when the contextual regularities are based on the semantic-category membership of the constituents of the context rather than on their specificity. To this end, we made the evenness/oddness property of the context predict the target location. In these experiments, then, it was no longer the elements of the context themselves that predicted the target location but the conceptual property of evenness/oddness.

EXPERIMENT 2

In Experiment 2, the evenness/oddness property of the context predicted the target location. The experimental principle was the same as in Experiment 1. The subject's task was to detect the target, 13 or 28, among a set of 16 context numbers. Each block of trials included predictive and nonpredictive trials. However, in half of the predictive trials the target context was composed solely of even numbers, and in the other half it was composed solely of odd numbers. When the context was even, the target appeared in a predefined area of the display (e.g., on the left); when the context was odd, the target appeared in the opposite area of the display (e.g., on the right). In the nonpredictive trials, the context had as many even numbers as odd ones and the target could appear in one or the other of the two display areas. The two areas chosen as potential target locations are shown in Figure 3.

Method

Subjects

Twenty-six students from the Science University of Marseille, France, participated in the experiment (12 women and 14 men, mean age 24).

Apparatus

The experimental apparatus was the same as in Experiment 1.

Stimuli

The target to be detected was 13 or 28. A trial always contained a target. The target could appear in one of eight predefined locations on the 8×6 grid (see Figure 3). To make the regularity more salient, all eight locations were limited to two areas of the display. The target appeared among 16 two-digit

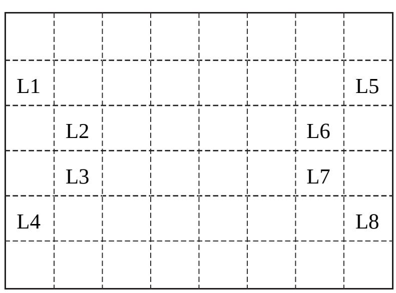

Figure 3. Target locations used in the invisible grid of Experiments 2 and 3.

numbers, from 10 to 29 excluding numbers comprising the digits 3 and 8. These 16 context numbers were distributed randomly across the grid.

Procedure

The experimental procedure was the same as in Experiment 1, unless otherwise indicated.

Search task. The subjects were instructed to quickly determine whether the target present was 13 or 28. The search task consisted of 24 blocks of 16 trials, making 384 trials in all. There were eight predictive trials and eight nonpredictive trials in each block, presented in random order.

Among the predictive trials, four were "even predictive" trials in which all context numbers were even, and four were "odd predictive" trials in which all context numbers were odd. For half of the subjects, the even contexts were associated with the target located on the left side of the display (locations L1, L2, L3, and L4 in Figure 3), and the odd contexts were associated with the target located on the right side of the display (locations L5, L6, L7, and L8 in Figure 3). For the other half of the participants, the sides were reversed. The 16 numbers that defined the even or odd predictive contexts were randomly drawn with replacement from the set of eight even numbers 10, 12, 14, 16, 20, 22, 24, and 26 or from the set of eight odd numbers 11, 15, 17, 19, 21, 25, 27, and 29, respectively.

On the nonpredictive trials, the target context was composed of eight even numbers and eight odd numbers. To ensure that the contexts on these trials would not be more heterogeneous than on the consistent trials, each context could contain only eight different numbers (four even and four odd).

Verbalization-then-recognition task. After the detection task, the participants were asked the same questions as in Experiment 1, along with the following additional question: "Did you notice that a rule predicted the target location?" The recognition task consisted of a new block of 32 trials, 16 generated in the same way as in the detection task, 8 counterpredictive trials, and 8 nonpredictive filler trials. In the counterpredictive trials, the target was located in the opposite area as in the visual search task (i.e., if in the search task the target in predictive odd contexts was located in the right part of the display, then the target was located in the left part). The instructions given to the participants were the same as in Experiment 1.

Results

Search task. In both the predictive and nonpredictive trials, the error rates were below 1.5%, so as above, the error data was not analysed. The blocks of trials were grouped into epochs of four consecutive blocks. This broke the test phase down into six epochs. RTs on errors, and all RTs above the mean plus three standard deviations, were discarded from the means. This procedure eliminated about 1.6% of the correct-answer RTs.

A repeated-measures ANOVA was conducted with condition (predictive vs. nonpredictive trials) and epoch (1–6) as within-subject factors. The RTs for the two conditions are plotted in Figure 4. The results yielded a condition effect, $F(1, 25) = 5.049$, $p < .05$, an epoch effect, $F(5, 125) = 21.693$, $p < .001$, and an Epoch × Condition interaction, $F(5, 125) = 2.404$, $p < .05$.

Verbalization-then-recognition task. At the end of the experiment, none of the 26 subjects mentioned evenness or oddness, so they were all given the recognition test. The percentages of "familiar" answers were analysed. An ANOVA with repeated measures yielded no significant difference in the percentage of "familiar" answers between the predictive (55%), nonpredictive (54%), and counterpredictive (56%) conditions, $F(2, 50) < 1$.

Discussion

The aim of this experiment was to trigger contextual cueing effects based on a semantic-category type of contextual regularity. The results obtained for the visual search task indicated target-detection facilitation on predictive trials when the evenness/oddness property of the context predicted the target location. On the other hand, the data from the verbalization-then-recogni-

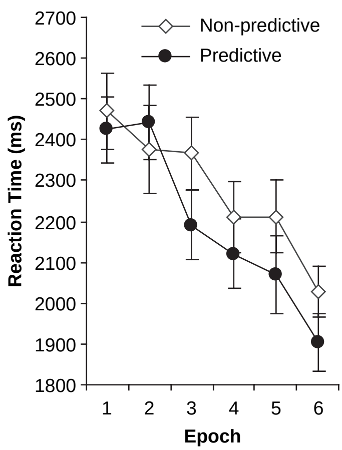

Figure 4. Mean target-detection reaction time in the nonpredictive and predictive conditions of Experiment 2, by epoch. The error bars represent the *SEM* ($N = 26$).

tion task indicated no difference between the three experimental conditions. These results suggest implicit learning based on the semantic-category membership of the context.

However, these findings alone are not sufficient to firmly conclude that there was a contextual cueing effect based on semantic categorization. As in Experiment 1, this effect may have been caused by the specific set of items that happened to be odd or even. Indeed, the contextual elements were randomly drawn from particular lists. Thus, the subjects may have simply learned the regularities based not on the evenness/oddness property but on the specific elements of the context that covaried with the abstract property manipulated. In order to unequivocally establish a categorical context cueing effect, in Experiment 3, we modified the design by introducing a transfer phase during the search task. The purpose of Experiment 3 was to examine whether contextual cueing could be transferred to a new set of numbers that was different from the one used at the beginning of the search task.

EXPERIMENT 3

The aim of Experiment 3 was to make sure that the contextual cueing effect we observed was indeed based on the category membership of the numbers, i.e., their oddness or evenness, and not on specific associations between a particular set of numbers and target locations. To this end, we introduced a transfer phase during the search task. Because Experiment 2 revealed that contextual cueing took place during the third epoch, the transfer phase was implemented in the third epoch. This phase had new odd and even numbers that were different from the ones used in Epochs 1 and 2. Hence, it was context evenness or oddness that predicted the target location and no longer the contextual elements themselves. We hypothesized that if a contextual cueing effect occurs during this third epoch, then the effect can be considered as a categorical cueing effect.

Method

Subjects

Twenty-eight students from the Science University of Marseille, France, participated in the experiment (13 women and 15 men, mean age 21).

Apparatus

The experimental apparatus was the same as in Experiment 1.

Stimuli

The target to be detected was 13 or 28. The 16 context numbers were drawn randomly with replacement among the following numbers: 11, 15, 21, and 25, or 17, 19, 27, and 29 for the odd numbers, and among the following numbers: 10, 12, 20, and 22, or 14, 16, 24, and 26 for the even numbers.

Procedure

The experimental procedure was the same as in Experiment 2, with the following changes.

Search task. The search task consisted of 12 blocks of 16 trials, which made three epochs. The third epoch was the transfer phase. One subset of context numbers was used in the first two epochs, and another subset was used in the third epoch (transfer phase). For half of the subjects, in the predictive trials of the first two epochs (eight blocks of 16 trials), the context numbers were randomly drawn with replacement from the odd subset 11, 15, 21, 25 or the even subset 14, 16, 24, 26. The nonpredictive trials were defined in the same way as in Experiment 2, with 11, 15, 21, 25 and 14, 16, 24, 26 as the odd and even subsets, respectively. In the predictive trials of the third epoch (four blocks of 16 trials), the context numbers were randomly drawn with replacement from the new odd subset 17, 19, 27, 29 or from the new even subset 10, 12, 20, 22. For the other half of the subjects, the experimental design was reversed.

Verbalization-then-recognition task. After the detection task, the participants were asked the same questions and performed the same recognition task as in Experiment 2 with the contextual numbers used in the first two epochs of the search task.

Results

Search task. In both the predictive and nonpredictive trials, the error rates were below 1.5%. The correct RTs above the mean plus three standard deviations were discarded (1.6%). The blocks of trials were grouped into three epochs, each epoch including four blocks of trials. The third epoch was the transfer phase. A repeated-measures ANOVA was conducted with condition (predictive vs. nonpredictive trials) and epoch (1–3) as within-subject factors. The RTs of the three epochs are plotted in Figure 5. The results yielded an epoch effect, $F(2, 54) = 5.041$, $p < .01$, no overall condition effect, $F(1, 27) < 1$, and an Epoch $\times$ Condition interaction, $F(2, 54) = 3.318$, $p < .05$. Partial analyses revealed a significant condition effect on Epoch 3 only, $F(1, 27) = 7.43$, $p < .05$.

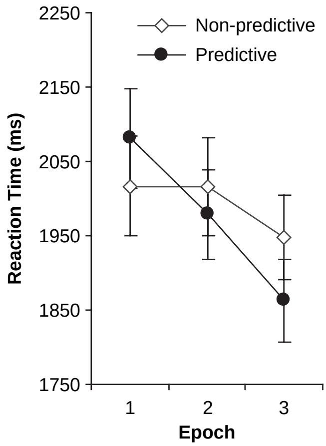

Figure 5. Mean target-detection reaction time in the nonpredictive and predictive conditions of Experiment 3, by epoch. The error bars represent the *SEM* ($N = 28$).

Verbalization-then-recognition task. None of the subjects mentioned evenness or oddness, so they all took the recognition test. An ANOVA with repeated measures yielded no significant difference in the percentage of "familiar" answers between the predictive (50%), nonpredictive (55%), and counterpredictive (50%) conditions, $F(2, 54) = 1.29$, $p = .284$.

Discussion

The aim of this experiment was to ensure that contextual cueing could be based on a semantic-category type of contextual regularity. The results indicated a contextual cueing effect even when new sets of numbers were used on the third epoch, i.e., different from those used in the first two epochs. These results show that the contextual cueing effect was based on the semantic-category property of evenness/oddness.

Moreover, not only were the subjects unable to verbalize the categorical regularities at play, they also could not differentiate predictive from nonpredictive or counterpredictive trials, i.e., ones in which the target was located on the wrong side of the screen. Thus, even when the regularities were based on a categorical property—here, evenness/oddness—none of the participants were able to outwardly express the regularity or even make use of it on a recognition task. These results showed that participants could learn the association between a categorical property (e.g., the concept of evenness/oddness) and a target location in an implicit way. They were capable of using that association in a target-detection task, in such a way that they accessed the target location more quickly, while nonetheless being unable to state the category-based regularity or use it on a recognition task.

GENERAL DISCUSSION

The goal of the present study was to determine whether, during a visual analysis, observers are able to implicitly learn contextual regularities generated by specific features as well as by general semantic-category features. The results provided evidence both of implicit learning based on the specific elements of the context (Experiment 1) and of implicit learning based on the semantic-category membership of the contexts (Experiments 2 and 3).

The results of Experiment 1 extend the contextual cueing effects obtained by Chun and Jiang (1999) and Endo and Takeda (2004) to cases where the regularities in the context are defined by the specificity of the contextual elements, independently of their spatial layout. The main contribution of this experiment was that it demonstrated associative learning that linked the specificity of the context's constituents to the target location, even when nonpredictive contexts were repeatedly presented across the search task. Experiment 2 showed that a contextual cueing effect could also occur when there were contextual regularities based on a categorical property, namely, the evenness/oddness of the context numbers. However, the observed learning could have been based on specific contextual elements that covaried with the oddness/evenness property. In Experiment 3, after some learning trials, a transfer phase using new sets of context numbers (different from those used in the first part of the search task) was introduced. The results showed that a contextual cueing effect nevertheless occurred during the transfer phase, indicating that the contextual cueing effect was in fact based on the categorical property of oddness/evenness. These results suggest that contextual cueing effects are not confined to cases where the specific features of the contextual elements are taken into account. They can therefore be generalized to more conceptual aspects of the context, as in the present case where they resulted from the semantic categorization of the context numbers. Thus, to detect a target as quickly as possible, the visuocognitive system relied either on the specific features of the context's constituents or on their categorical properties, depending on their predictive power.

Our study also pointed out the unconscious nature of the learning that took place here. In neither of the experiments conducted for this study did any of the subjects say they had noticed the regularities that predicted the target location, nor were any of them capable of making use of those regularities to discriminate predictive trials from nonpredictive or counter-predictive ones on the subsequent recognition task. The implicit learning therefore did not stem from any potential difficulty the subjects might have had in verbalizing their knowledge, but was indeed the result of their inability to access that knowledge in a conscious way. Thus, the observed contextual cueing effects were the outcome of implicit learning (Cleeremans et al., 1998), even when the contextual regularities were clearly based on the semantic-category properties of the contextual elements rather than on their specific properties. These results differ from those reported by Brockmole and Henderson (2006) with real-world scenes. In fact, Brockmole and Henderson showed that cueing was facilitated by semantic memory for scene content, but also that memory for scene–target covariation was in this case explicit. Our study demonstrates that learning based on semantic regularities was not necessarily associated with awareness of such regularities.

In the literature on visual-scene analysis, many authors have agreed that visual representations are supported by a *scene schema* stored in LTM (Henderson & Hollingworth, 1999; Rensink, 2000). For Rensink, this aspect of representational content is a very fundamental one, since it provides the frame of reference that guides the observer's attention toward the desired objects in the scene. However, the learning mechanisms that construct scene schemas are poorly defined. In our study, the participants seem to have learned implicitly where the element to be detected was located, not only in specific contexts but also in contexts defined by the semantic-category membership of their constituents. Thus, during the analysis of an image or a visual scene, the visuocognitive system seems to be able to implicitly encode and store not only spatial relationships between the specific features of contextual elements, but also relationships bearing on certain categorical properties of those elements. This implicit knowledge, acquired through the extraction of cooccurrences based on perceptual properties (see also Fisher & Aslin, 2001) or on more conceptual properties of the elements present in the scene, could therefore be a part of the process that builds and stores scene schemas in LTM. Such scene schemas would guide attentional processing in an efficient and automatic way. Both implicit learning and retrieval mechanisms should contribute to accounting for the richness and adapted nature of our behaviours, even ones that are not conscious or controlled.

REFERENCES

Biederman, I. (1972). Perceiving real-world scenes. *Science*, *177*, 77–80.

Biederman, I., Mezzanotte, R. J., & Rabinowitz, J. C. (1982). Scene perception: Detecting and judging objects undergoing relational violations. *Cognitive Psychology*, *14*, 143–177.

Boyce, S. J., & Pollatsek, A. (1992). An exploration of the effects of scene context on object identification. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*, 227–242.

Boyce, S. J., Pollatsek, A., & Rayner, K. (1989). Effect of background information on object identification. *Journal of Experimental Psychology: Human Perception and Performance*, *15*, 556–566.

Brockmole, J. R., & Henderson, J. M. (2006). Using real-world scenes as contextual cues for search. *Visual Cognition*, *13*, 99–108.

Chua, K.-P., & Chun, M. M. (2003). Implicit scene learning is viewpoint dependent. *Perception and Psychophysics*, *65*, 72–80.

Chun, M. M., & Jiang, Y. (1998). Contextual cueing: Implicit learning and memory of visual context guides spatial attention. *Cognitive Psychology*, *36*, 28–71.

Chun, M. M., & Jiang, Y. (1999). Top-down attentional guidance based on implicit learning of visual covariation. *Psychological Science*, *10*, 360–365.

Chun, M. M., & Jiang, Y. (2003). Implicit, long-term spatial contextual memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*, 224–234.

Chun, M. M., & Wolfe, J. M. (2001). Visual attention. In B. Goldstein (Ed.), *Blackwell handbook of perception* (pp. 272–310). Oxford, UK: Blackwell.

Cleeremans, A., Destrebecqz, A., & Boyer, M. (1998). Implicit learning: News from the front. *Trends in Cognitive Sciences*, *2*, 406–416.

Endo, N., & Takeda, Y. (2004). Selective learning of spatial configuration and object identity in visual search. *Perception and Psychophysics*, *66*, 293–302.

Fisher, J., & Aslin, R. N. (2001). Unsupervised statistical learning of higher-order spatial structures from visual scenes. *Psychological Science*, *12*, 499–504.

Friedman, A. (1979). Framing pictures: The role of knowledge in automatized encoding and memory for gist. *Journal of Experimental Psychology: General*, *108*, 316–355.

Gibson, E. J. (1969). *Principles of perceptual learning and development*. New York: Appleton-Century-Crofts.

Gordon, R. D. (2004). Attentional allocation during the perception of scenes. *Journal of Experimental Psychology: Human Perception and Performance*, *30*, 760–777.

Henderson, J. M., & Hollingworth, A. (1999). High-level scene perception. *Annual Review of Psychology*, *50*, 243–271.

Henderson, J. M., Weeks, P. A., Jr., & Hollingworth, A. (1999). Effects of semantic consistency on eye movements during scene viewing. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 210–228.

Hollingworth, A., & Henderson, J. M. (1998). Does consistent scene context facilitate object perception? *Journal of Experimental Psychology: General*, *127*, 398–415.

Irwin, D. E., & Andrews, R. V. (1996). Integration and accumulation of information across saccadic eye movements. In T. Inui & J. L. McClelland (Eds.), *Attention and performance XVI: Information integration in perception and communication* (pp. 125–155). Cambridge, MA: MIT Press.

Itti, L. (2003). Visual attention. In M. A. Arbib (Ed.), *The handbook of brain theory and neural networks* (2nd ed., pp. 1196–1201). Cambridge, MA: MIT Press.

Jiang, Y., & Leung, A. W. (2005). Implicit learning of ignored visual context. *Psychonomic Bulletin and Review*, *12*, 100–106.

Levin, D. T., & Simons, D. J. (1997). Failure to detect changes to attended objects in motion pictures. *Psychonomic Bulletin and Review*, *4*, 501–506.

Luck, S. J., & Vogel, E. K. (1997). The capacity of visual working memory for features and conjunctions. *Nature*, *390*, 279–281.

Mandler, J. M., & Parker, R. E. (1976). Memory for descriptive and spatial information in complex pictures. *Journal of Experimental Psychology: Human Learning and Memory*, *2*, 38–48.

Mandler, J. M., & Ritchey, G. H. (1977). Long-term memory for pictures. *Journal of Experimental Psychology: Human Learning and Memory*, *3*, 386–396.

Olson, I. R., & Chun, M. M. (2001). Temporal contextual cuing of visual attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *27*, 1299–1313.

Olson, I. R., & Chun, M. M. (2002). Perceptual constraints on implicit learning of spatial context. *Visual Cognition*, *9*, 273–302.

Palmer, S. E. (1975). The effects of contextual scenes on the identification of objects. *Memory and Cognition*, *3*, 519–526.

Peterson, M. S., & Kramer, A. F. (2001). Attention guidance of the eyes by contextual information and abrupt onsets. *Perception and Psychophysics*, *63*, 1239–1249.

Rensink, R. A. (2000). The dynamic representation of scenes. *Visual Cognition*, *7*, 17–42.

Rensink, R. A. (2002). Change detection. *Annual Review of Psychology*, *53*, 245–277.

Schacter, D. L. (1987). Implicit memory: History and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *13*, 501–518.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search and attention. *Psychological Review*, *84*, 1–66.

Shinoda, H., Hayhoe, M. M., & Shrivastava, A. (2001). What controls attention in natural environments? *Vision Research*, *41*, 3535–3545.

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, *12*, 97–136.

Manuscript received November 2005
Manuscript accepted February 2006
First published online June 2006