Mem Cogn (2014) 42:225–236
DOI 10.3758/s13421-013-0355-0

The emergence of explicit knowledge from implicit learning

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Published online: 20 September 2013

Abstract Substantial evidence has highlighted the ability of observers to incidentally extract statistical contingencies present in visual environments. This study examined whether the knowledge extracted regarding statistical contingencies is unconscious initially, even when it becomes fully accessible to conscious awareness after extensive training. Using a "typical" contextual cuing procedure adapted to real-world scenes, we first observed that, after extensive training in searching for a target within repeated scenes, knowledge about regularities was associated with conscious awareness (Experiment 1). However, both subjective and objective measures of consciousness revealed that in the early phase of training, learning of regular structures first takes place at an unconscious level (Experiments 2 and 3). These results are discussed in the light of the causal relationships between learning and consciousness.

Keywords Contextual cuing · Implicit learning · Explicit learning · Consciousness · Unconscious knowledge

Over the past 2 decades, a substantial amount of evidence has highlighted the remarkable ability of observers to extract and use statistical contingencies present in structured stimulus environments (e.g., Chun & Jiang, 1998; Fiser & Aslin, 2001; Saffran, Aslin, & Newport, 1996; for a review, see Thiessen, Kronstein, & Hufnagle, 2012). In this respect, more and more models of cognition and development refer to *statistical learning* to account for sophisticated human behaviors such as language acquisition, motor skill, or object recognition and navigation in complex and dynamic environments (e.g., Gopnick & Wellman, 2012; Oliva & Torralba, 2007; Perruchet & Pacton, 2006; Thiessen et al., 2012). Of interest, statistical learning mechanisms have often been shown to operate implicitly, since they take place without intention to learn and individuals are not able to verbally report or consciously access the resulting knowledge (e.g., Chun & Jiang, 2003; Fiser & Aslin, 2001; Turk-Browne, Jungé, & Scholl, 2005; however, cf. Smyth & Shanks, 2008). Yet, although there is no doubt that our sensitivity to statistics present in the real world develops mostly incidentally, we can nevertheless consciously access the regularities responsible for adaptation in many situations. The present study investigates how the conscious or unconscious nature of knowledge acquired during the analysis of visual real-world scenes evolves during learning. More specifically, we tested the hypothesis that even when knowledge related to statistical contingencies is fully accessible to conscious awareness after extensive training, incidental learning tends to first give rise to unconscious knowledge.

By revealing differential conscious or unconscious knowledge depending on the testing environments, the contextual cuing paradigm provides a powerful tool for testing this hypothesis (e.g., Brockmole & Henderson, 2006a; Chun & Jiang, 1998). The general principle of the contextual cuing paradigm consists of presenting regularities within search displays that predict the target's location and implicitly exposing participants to these regularities throughout the course of the task. One advantage of this method is that knowledge about regularities is indirectly measured through a benefit in search times, and consequently, its evaluation does not rely on a direct memory task or on the subjective judgment of the participant, thereby revealing the existence of both conscious and unconscious knowledge.

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In the classic task of the contextual cuing paradigm, participants are instructed to search for a *T* (target) among *L*s (distractors) and report whether the top of the T points left or right. Half of the configurations are systematically repeated across many blocks of trials, while the other half are novel. A progressive benefit for search time, named *contextual cuing*, is typically observed in the repeated contexts, which are predictive of the target's location, as compared with the novel contexts. Yet, at the end of the search task, participants rarely report having noticed that some displays were repeated across the task, and their performance in a final direct memory task (i.e., recognition and/or target generation) is typically at or near chance levels. This finding is taken to suggest that the contextual cuing effect results from implicit learning (Chun & Jiang, 1998, 2003; but see Smyth & Shanks, 2008).

Since Chun and Jiang's original work, contextual cuing effects resulting from implicit knowledge acquisition have been extended to a wide range of visual regularities (e.g., Chun & Jiang, 1999; Goujon, 2011; Goujon, Didierjean, & Marmèche, 2007, 2009; Olson & Chun, 2002). Nonetheless, when the predictive contexts are repeated real-world scenes (Brockmole & Henderson, 2006a), contextual cuing effects differ in both quantitative and qualitative aspects. For example, repeated contexts defined by complex real-world scenes give rise to greater benefits than do contexts made up of letters (Brockmole & Henderson, 2006a, 2006b), and the learning effects are clearly associated with conscious awareness of the predictive regularities at the end of the session. Indeed, not only do the participants reliably recognize the repeated images among new pictures, but also they are capable of reporting with high accuracy the associated target positions in a target generation task (for similar results with meaningless and visually complex images, see Goujon, Brockmole, & Ehinger, 2012).

This evidence that awareness and learning behavior depend critically on the testing environments raises the question of whether learning mechanisms involved in contextual cuing within repeated complex images are fundamentally different in nature from those involved in contextual cuing within repeated simple stimuli arrays. One hypothesis is that the early and strong contextual cuing effects observed in complex images rely on the explicit detection of the salient regularities. In this view, learning of spatial regularities related to the *context–target-location* associations would be concomitant with conscious awareness and might involve a declarative memory system, which might contrast with a nondeclarative memory system involved during searching within simple stimuli arrays (e.g., Manns & Squire, 2001).

In previous studies using real-world scenes (Brockmole & Henderson, 2006a; Goujon et al., 2012), however, consciousness was assessed following extensive training (16 or 17 exposures to the same images), while a benefit began occurring early in the session (after only one or two repetitions of images). Thus, it remains possible that in real-world scenes, as in arbitrary displays, learning and the exploitation of regularities may first take place at an unconscious level. This raises the question of whether conscious awareness of regularities presented in real-world scenes always accompanies learning and, consequently, precedes contextual cuing or whether learning and contextual cuing precedes awareness of regularities. To address this issue, we examined the nature of knowledge acquired in the first stages of training, using a direct memory task—a target generation task—implemented at the beginning of learning.

If awareness is found to precede contextual cuing, it would emphasize the role of consciousness in establishing learning benefits in repeated visually rich images (e.g., Goujon et al., 2012). In contrast, if a contextual cuing effect is observed before the explicit awareness of regularities, this will open avenues to explore the possibility that conscious awareness of regularities may emerge from unconscious knowledge. On this view, conscious and unconscious knowledge might be generated by common memory system(s) but would differ in the coherence and the stability of the representation associated with the activation of the underlying trace (Cleeremans & Jiménez, 2002; Overgaard, Rote, Mouridsen, & Ramsøy, 2006). Hence, the aim of the present study was to investigate whether, in a context of incidental learning, knowledge that is fully accessible to conscious awareness following extensive training tends to nevertheless initially emerge at an unconscious level. The novelty of the present study is that the testing materials yielded unambiguous conscious awareness of regularities after 17 exposures, despite the incidental character of the learning procedure. The clear conscious access to knowledge after extensive training provides interesting avenues for studying the causal relationships between learning and consciousness and between implicit and explicit learning/memory. This study constituted preliminary investigations of these issues.

This study included three experiments, which were divided into two parts. In the first part of each experiment, participants had to search for a T or an L embedded within photographs of real-world scenes that were repeated in each block of trials (repeated condition) or presented only once across the task (unrepeated condition). In the second part, the conscious status of acquired knowledge during the search task was assessed with a target generation task. This objective direct memory task was supplemented with a subjective measure: After each target placement, the participants had to indicate on a 5-point scale their confidence in the precision of their response. In Experiment 1, the speed of learning in the scenes used in the present study was characterized through a visual search task that included 17 blocks of trials. In Experiments 2 and 3, the explicit memory task was implemented in the early phase of training (i.e., at the end of block 3 and at the end of block 2, respectively).

Experiment 1

The aim of Experiment 1 was to reproduce explicit contextual cuing effects already observed with repeated real-world scenes (Brockmole & Henderson 2006a, b) and to determine the speed of learning with the present materials before examining the nature of knowledge at the beginning of learning in Experiments 2 and 3.

Method

Participants

Thirteen participants (mean age = 21;2 years, *SD* = 2;11 years) performed a visual search that was immediately followed by an explicit memory task. All the participants volunteered for the experiment and reported normal or corrected-to-normal visual acuity.

Search task

The stimulus materials used in the search task consisted of 152 full-color photographs of real-world scenes. Eight were used for the practice block, and 144 for the experimental trials. Within each image, a single gray T or L was presented in 9-point Arial font. These letters constituted the target of the visual search task and were located in one of eight possible and equally frequent (x,y) coordinates. The luminance of the target was adjusted across images to approximately equate its contrast against the local background.

Participants were instructed to search for a T or an L as quickly as possible in each scene and to press the corresponding key upon identification of the target (T vs. L). The search task included 17 blocks, each consisting of eight repeated trials and eight unrepeated trials. The eight repeated trials were eight different search scenes that were presented once in each block—that is, 17 times across the experiment. Within each repeated scene, the target location was held constant, but its identity (and the corresponding response key) was randomly determined. The unrepeated trials presented a search scene that was shown only once during the task. Eight different target locations were used for the eight unrepeated trials of each block.

The experiment began with the instructions, which were followed by a practice block of 8 trials aimed at familiarizing participants with the procedure. The participants then moved on to the experimental trials. The 17 predesigned blocks of trials were presented randomly, as were the 16 trials within each block. Participants pressed the space bar to start the experiment. After a 500-ms delay, a scene containing a target appeared on the screen. Participants had to search as quickly as possible for the target and press the corresponding key for that target letter. The participant's response triggered a 500-ms display of a white screen with a blue dot in the middle. A break was programmed at the end of each block.

Target generation task

After completing the 17 blocks in the search task, awareness for the repeated scenes was assessed. Participants were informed that some scenes were repeated during the session and were then presented with a target generation task. The task included 32 trials presenting the 8 repeated scenes, 8 unrepeated scenes (seen once during the search task), and 16 entirely new scenes (never seen during the search task). Importantly, none of those scenes contained a target. For each image, observers were instructed to use a mouse trackball to move a dot to the location at which they remembered the target being presented. After each target placement, participants reported their confidence about the precision of their response on a 5-point scale, where 1 corresponded to *random response*, 2 to *not confident*, 3 to *low confident*, 4 to *confident*, and 5 to *highly confident*.

The experiment was programmed using E-Prime software, and the scenes were displayed at a resolution of 800 × 600 pixels in 32-bit color on a 15-in. screen, with a refresh rate of 60 Hz. The participants were seated approximately 50 cm from the screen.

Results and discussion

Search task

Trials were excluded from analysis if a response was not made within 20 s (2.04 % and 0.03 % in the unrepeated and repeated conditions, respectively) and/or was incorrect (1.13 % and 1.86 % in the unrepeated and repeated conditions, respectively). For each participant, a separate mean search time was calculated for each block and each condition tested. The resulting mean search times are presented in Fig. 1. Data were

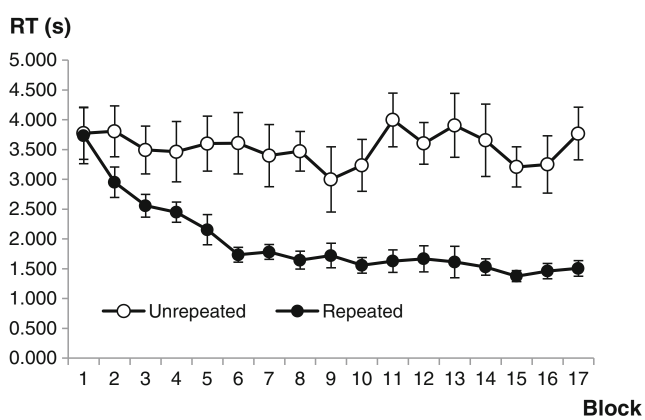


Fig. 1 Mean response times in each block for the repeated and unrepeated conditions in Experiment 1. The error bars show the standard errors of the means (N = 13)

analyzed using a repeated measures ANOVA with condition (repeated vs. unrepeated contexts) and block (1–17) as within-subjects factors. The results showed a main effect of block, $F(16, 192) = 5.49$, $p < .001$, $\eta^2_{partial} = .31$, a main effect of condition, $F(1, 12) = 18.02$, $p < .001$, $\eta^2_{partial} = .60$, and a significant block × condition interaction, $F(16, 192) = 4.15$, $p < .001$, $\eta^2_{partial} = .26$. Post hoc analyses indicated that the facilitating effect in the repeated condition, as compared with the unrepeated condition, was significant from block 2 and remained significant on the next blocks (all ps < .005, Fisher's least significant difference [LSD]).

Generation task

To evaluate the accuracy of observers' memory for the context–target-location associations, the distance between the actual target location and the observer's placement of the target was measured. For the 16 new pictures, an arbitrary referencing target location was determined from the eight coordinates used in the search task. The average placement error and confidence rating in each condition are summarized in Table 1. A one-way repeated measures ANOVA was conducted on each dependent variable (placement error and confidence rating), with condition (repeated vs. unrepeated vs. new) as a within-subjects factor. The ANOVA showed a main effect of condition on both variables: placement error, $F(2, 24) = 65.67$, $p < .001$, $\eta^2_{partial} = .85$, and confidence rating, $F(2, 24) = 147.00$, $p < .001$, $\eta^2_{partial} = .92$. Pairwise comparisons indicated that the repeated condition differed significantly from the unrepeated and new conditions on both variables (all ps < .001; for placement errors, $\eta^2_{partial} = .86$ and $\eta^2_{partial} = .88$, respectively; for confidence ratings, $\eta^2_{partial} = .93$ and $\eta^2_{partial} = .94$, respectively). The unrepeated and new conditions differed on the confidence rating, $p < .001$, $\eta^2_{partial} = .71$, but not on the target placement error, $p = .13$, $\eta^2_{partial} = .27$. Furthermore, a strong correlation was observed between the placement errors and the confidence ratings across the eight repeated scenes, $r = -.63$, $p < .001$. Thus, the target placement error appeared to be a reliable indicator of the participants' explicit knowledge. The placement errors as a function of the confidence ratings are presented in the Appendix (Panel a), as well as the percentage of responses corresponding to each confidence rating (1–5).

Table 1 Averaged placement errors and confidence ratings as a function of trial condition (repeated, unrepeated, and new) for Experiment 1 (after 17 blocks), Experiment 2 (after 3 blocks), and Experiment 3 (after 2 blocks)

Task	Experiment	Condition		
		Repeated	Unrepeated	New
Placement error	17 blocks	113 (27)	361 (13)	403 (15)
	3 blocks	271 (26)	393 (29)	388 (12)
	2 blocks	325 (21)	336 (16)	361 (18)
Subjective confidence rating	17 blocks	3.90 (0.18)	1.88 (0.09)	1.23 (0.06)
	3 blocks	2.38 (0.21)	1.94 (0.15)	1.25 (0.10)
	2 blocks	2.37 (0.15)	1.91 (0.13)	1.46 (0.06)

Note. The placement errors are reported in pixels. The standard errors of the means are presented in parentheses.

The results in both the search task and the explicit memory task closely resemble those observed in previous studies using real-world scenes (e.g., Brockmole & Henderson, 2006a). A contextual cuing effect emerged very early during the search task (block 2), and this benefit was magnified over repetitions to reach an asymptote around block 10. After 17 blocks, the cuing effect was very strong and reliable (55 % faster responses in the repeated condition than in the unrepeated condition, $\eta^2_{partial} = .67$), which was associated with awareness of context–target-location associations (average error of 113 pixels in the repeated vs. 403 pixels in the unrepeated condition, $\eta^2_{partial} = .86$). Except for 3 participants, the confidence ratings related to the target placement in the generation task were higher than 1 for all the repeated items (87.5 % of the total responses in the repeated condition). This suggests that, after 17 blocks of trials, contextual cuing in real-world scenes was mostly associated with some kind of consciousness of regularities. In addition, the target placement errors were significantly correlated with the contextual cuing effects measured in block 17 when the analysis included all repeated items, $r = -.29$, $p < .001$. According to the logic of dissociation/association, this result suggests that performance in both the search task and the target generation task is supported by the same source of knowledge, which is accessible to conscious awareness (Shanks & Berry, 2012). Panel a in the Appendix summarizes the cuing effects and the target placement errors as a function of the confidence ratings in the target generation task.

In sum, as in previous studies using similar materials, a strong contextual cuing effect emerged very early during the task—block 2 onward—and knowledge related to context–target-location associations was clearly accessible to conscious awareness after 17 exposures (1 in each of the 17 blocks). As a reminder, the question at hand in the present study concerns the nature of learning in the first stage of training. Does conscious awareness always precede contextual cuing in repeated real-world scenes, or does contextual cuing emerge before conscious awareness? To address this question, we assessed conscious awareness early in the experiment. Given the speed of learning observed in Experiment 1, the explicit memory task was implemented after the second block in a pilot experiment. However, the results of this experiment failed to provide evidence of a reliable contextual cuing effect in the second block, and performance in the target generation task was not above chance level. Thus, no conclusions could be made concerning the existence of implicit or explicit knowledge in block 2. That is why, in Experiment 2, we assessed awareness after 3 blocks of training, while learning was robust.

Experiment 2

In Experiment 2, the conscious or unconscious nature of knowledge acquired in the early phase of training was examined after three blocks of trials, at which point contextual learning was already found to be reliable in Experiment 1. Furthermore, to ensure that the contextual cuing effect observed in Experiment 2 specifically resulted from learning of context–target-location associations, rather than from general facilitation in perceptual processing of familiar contexts, we included a control group in which the scenes still repeated once per block but the target location varied each time (this is called a *shuffled* condition; see Chun & Jiang, 1998, Experiment 3, for a similar procedure).

Method

Fourteen participants took part in Experiment 2 in the experimental group (mean age: 20;8 years, *SD* = 3;3 years), and 20 participants took part in the control group (mean age: 21;3 years, *SD* = 4;5 years). The methods and procedure were similar to those used in Experiment 1, except that the search task included only three blocks of trials. The materials included the same 8 repeated scenes, in addition to 24 scenes belonging to the unrepeated condition. The task and the instruction were the same as in Experiment 1. The materials and the procedure of the explicit memory task were the same as in Experiment 1, except that only eight new images were used. Note that the unrepeated scenes selected for the memory task were all presented during the search task.

A control group including 20 participants (mean age: 21;3 years, *SD* = 4;5 years) was presented with a visual search task similar to the experimental group, with the same scenes repeated once per block, except that the target location within the repeated contexts was randomly "shuffled" each time it was presented. As in the unrepeated condition, in each block, the same eight potential target locations were randomly used through the eight shuffled trials.

Results and discussion

Search task

As in Experiment 1, trials were excluded from the analysis if a response was not made within 20 s (1.92 % and 1.60 % of trials in the unrepeated and repeated conditions, respectively, for the experimental group and 2.91 % and 2.08 % in the unrepeated and shuffled conditions, respectively, for the control group) and/or was incorrect (2.56 % and 3.20 % in the unrepeated and repeated conditions, respectively, in the experimental group and 3.75 % and 2.91 % in the unrepeated and shuffled conditions, respectively, in the control group). The mean search times are presented in Fig. 2a for the experimental group and in Fig. 2c for the control group. Two distinct repeated measures ANOVAs were conducted for each group, with condition (repeated images vs. unrepeated images for the experimental group and shuffled images vs. unrepeated images for the control group) and block (1–3) as within-subjects factors.

The repeated measures ANOVA conducted for the experimental group showed no significant condition effect, $F(1, 13) = 1.84$, $p = .196$, $\eta^2_{partial} = .12$, and no block effect, $F < 1$, $\eta^2_{partial} = .04$. However, the condition × block interaction was significant, $F(2, 26) = 11.95$, $p < .001$, $\eta^2_{partial} = .48$. Post hoc analyses revealed that the repeated scenes triggered shorter RTs than did unrepeated scenes in block 3, $p < .001$, $\eta^2_{partial} = .77$. This finding is in line with the reliable contextual cuing already observed in Experiment 1 in block 3, after two repetitions.

The repeated measures ANOVA conducted for the control group showed no significant condition effect, $F(1, 19) = 3.25$, $p = .09$, $\eta^2_{partial} = .15$, no block effect, $F < 1$, $\eta^2_{partial} = .03$, and no condition × block interaction, $F(2, 38) = 2.64$, $p = .08$, $\eta^2_{partial} = .12$. Nevertheless, contrary to Experiment 1 and to the experimental group, when the target location was variable in the repeated contexts (shuffled condition), an impairment of the search performance was observed in block 3 ($p < .05$, $\eta^2_{partial} = .20$; pairwise comparisons were not significant in blocks 1 and 2 [Fisher's LSD]).

This finding demonstrates that the contextual cuing effect observed in the experimental group was indeed due to learning of the associations between repeated contexts and the target location, and not to enhancing low-level perceptual processing of repeated images due to familiarity (for a similar argument based on eye movement data after 17 blocks, see Brockmole & Henderson, 2006b).

Target generation task

The average placement error and the average subjective confidence rating obtained in each condition for the experimental group are summarized in Table 1. A one-way repeated ANOVA conducted on each dependant variable showed that the three experimental conditions differed significantly on both dependant variables: error placement, $F(2, 26) = 12.06$, $p < .001$, $\eta^2_{partial} = .48$, and confidence rating, $F(2, 26) = 21.01$, $p < .001$, $\eta^2_{partial} = .62$. Pairwise comparisons indicated that the repeated condition differed significantly from the unrepeated and new conditions on both placement error (all ps < .001, $\eta^2_{partial} = .60$ and $\eta^2_{partial} = .59$, respectively) and confidence rating (all ps < .001, $\eta^2_{partial} = .44$ and $\eta^2_{partial} = .68$, respectively). The unrepeated and new conditions differed from each other on confidence rating, $p < .01$, $\eta^2_{partial} = .57$, but not on error placement, $p = .86$, $\eta^2_{partial} = .00$. Once again, the correlation between the target placement errors and the confidence ratings across the repeated scenes was significant, $r = -.45$, $p < .001$. The Appendix shows placement errors as a function of the confidence ratings (Panel b), as well as the percentage of responses corresponding to each confidence rating.

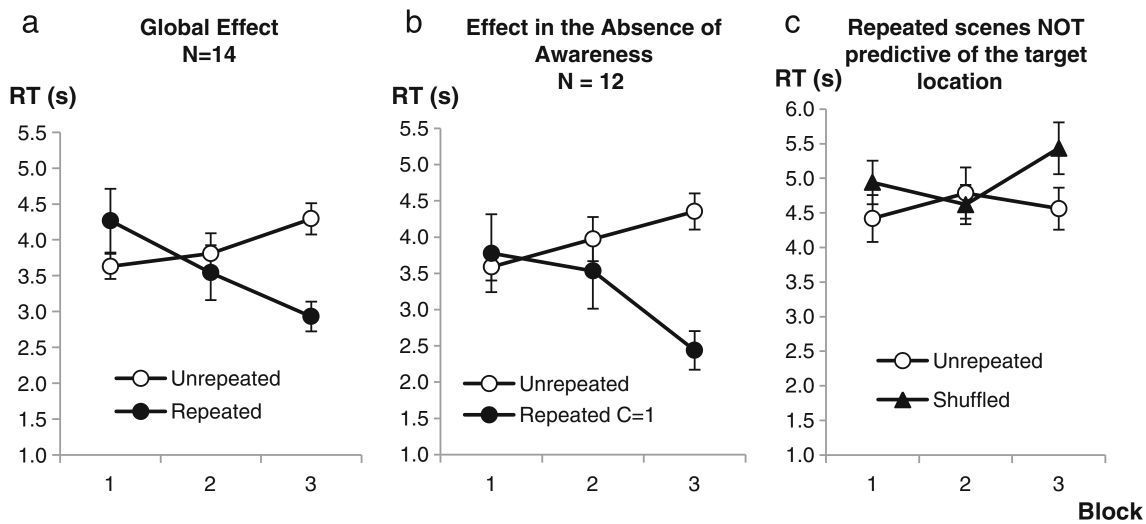


Fig. 2 a, b Mean response times for the test group in each block for the unrepeated and repeated conditions used in the global analysis (panel a; N = 14) and or those used in the analysis in absence of consciousness—that is, when the confidence ratings corresponded to random response in the generation task (panel b; N = 12; 2 participants were not included because they provided no confidence rating = 1 in the repeated condition). The error bars show the standard errors of the means. c Mean response times in each block for the shuffled and unrepeated conditions for the control group in Experiment 2 (N = 20). The error bars show the standard errors of the means

These results suggest that even after only three exposures, participants had acquired, at least in part, some explicit knowledge of the context–target location associations. Furthermore, the reliable degree of correspondence between objective and subjective measures in the generation task suggests that already after three exposures, the accuracy in the target placement was derived to some extent from explicit knowledge. However, it remains possible that participants might have developed both conscious and unconscious knowledge during the search task. The existence of conscious knowledge about certain scenes does not exclude the existence of unconscious knowledge about other scenes. To test this possibility, we evaluated whether a contextual cuing effect persisted in the absence of reported awareness about regularities.

Contextual cuing in the absence of awareness

In order to exclude explicit knowledge in the analysis of contextual cuing, we used the subjective confidence ratings obtained in the generation task. Recall that a confidence rating of 1 on the 5-point scale means that the participant claimed to have *randomly* placed the target within the scene during the generation task. A t-test showed that, for this lowest confidence rating, the average placement error did not differ from the average placement error in the entirely new scenes [406 vs. 388 pixels, respectively; $t(40) < 1$]. Note that these low-confidence trials were not rare but, rather, constituted about one third of all trials.

Given heated debates concerning a reliable assessment of the conscious or unconscious status of acquired knowledge during incidental learning (for a review, see Seth, Dienes, Cleeremans, Overgaard, & Pessoa, 2008), using confidence ratings to discard explicit knowledge from the analyses of search performance requires further justification. One criticism often made is that participants might have adopted a fairly high criterion for making a judgment greater than 1 (reflecting "random" choice). In addition, they might have given minimal thought to their confidence judgments on certain repeated scenes and pressed 1 even when they had some confidence in their target placement. If so, the *repeated confidence = 1* condition might be contaminated by a substantial amount of explicit knowledge. Nonetheless, the weak levels of performance in the target placement error in the repeated confidence = 1 condition in all experiments of the present study (see the Appendix) validates the reported feeling of the participants that, indeed, they had no conscious memory of the target location associated with those specific scenes. Thus, using a confidence rating of 1 seems to be a reliable index with which to exclude explicit knowledge from RT analyses.

To determine whether a contextual cuing effect nevertheless occurred in those specific repeated scenes with a confidence rating of 1 (repeated confidence = 1), for each participant, a separate mean search time was calculated for the repeated condition in each block. This procedure included 35 % of the total repeated items, after first excluding 2 participants who never provided a confidence rating of 1 in the repeated condition. A repeated measures ANOVA was conducted with condition (repeated confidence = 1 vs. unrepeated[1]) and block (1–3) as within-subjects factors. The mean search times for each condition and block are presented in Fig. 2b. The results showed a marginal effect of condition, $F(1, 11) = 4.13$, $p = .067$, $\eta^2_{partial} = .27$, no main effect of

[1] All the unrepeated scenes were included in the analysis.

block, $F < 1$, $\eta^2_{\text{partial}} = .06$, but a significant condition × block interaction, $F(2, 22) = 9.47$, $p < .001$, $\eta^2_{\text{partial}} = .46$. Post hoc analysis revealed a condition effect in block 3 (1.364 ms), $p < .001$, $\eta^2_{\text{partial}} = .75$. A substantial contextual cuing effect was thus observed despite random responses in the explicit memory task and, therefore, in the absence of consciousness of the predictive regularities. This result shows that knowledge is, at least in part, inaccessible to consciousness in the first stage of training. Panel b in the Appendix summarizes the averaged cuing effects and target placement errors as function of the confidence ratings in the target generation task.

Note, however, that analyses based on post hoc selection of trials must be interpreted cautiously (Perruchet & Amorim, 1992; Rünger, Nagy, & Frensch, 2009; Shanks & Berry, 2012; Shanks & Perruchet, 2002; Shanks, Wilkinson, & Channon, 2003). Evidence of learning through an indirect measure (e.g., a contextual cuing effect, in the present case), despite random performance in a direct memory task (e.g., in the target generation task), may emerge because independent sources of noise contribute to the two measures. RTs in the search task and the placement errors in the generation task are indeed susceptible to measurement error, and some component of this error is likely to be task dependent (in other words, uncorrelated between the two tests). Consequently, selecting items with a mean score of zero on one measure (target generation) might yield scores on the other measure that are greater than zero, merely because of the imperfect correlation between them (for a review, see Shanks & Berry, 2012).

However, this argument would have force only if the repeated confidence = 1 condition was significantly contaminated by explicit knowledge. If this was the case, we would have expected lower target placement error in the repeated condition than in the new condition, at least at a marginal level. However, there was no difference in the distribution of the target placement errors in the repeated confidence = 1 condition, as compared with the new condition (M = 406 pixels, SD = 201 pixels vs. M = 384 pixels, SD = 195 pixels, respectively; $F < 1$, Levene's test). In addition, despite substantial variance in RTs (M = 4,297 ms, SD = 3,597 ms, for all data points in the unrepeated condition [n = 108] and M = 2,963 ms, SD = 1,929 ms, for all data points in the repeated conditions [n = 107] in Block 3), the contextual cuing effect in block 3 in absence of awareness was very strong. Thus, the effect size was very large ($\eta^2_{\text{partial}} = .75$; i.e., the condition variable accounts for 75 % of variance in block 3 in the absence of awareness) and did not differ from the effect size observed in the global analysis ($\eta^2_{\text{partial}} = .77$).

Furthermore, in a pilot experiment mentioned above, performance in the target generation task was not above chance level at the end of block 2, suggesting that knowledge acquired after two presentations does not rise to the level of consciousness required to be reliably used in an explicit memory task. Because contextual cuing appears to usually already be robust in block 3 in experiments using similar materials (e.g., Experiments 1 and 2 in the present study; Brockmole & Henderson, 2006a, 2006b), we might assume that contextual cuing effects precede conscious detection of predictive regularities in real-world scenes.

Nonetheless, it is possible that contextual cuing in block 3 is a short-term effect and that the trace related to the scene–target-location associations quickly declines in memory. During the explicit memory task, participants might have forgotten the knowledge that they had just used consciously during the search task (Shanks & Perruchet, 2002). This hypothesis was tested in Experiment 3.

Experiment 3

Experiment 2 revealed the existence of a contextual cuing effect in block 3 even in the absence of conscious awareness of regularities—that is, when both the target placement errors and the confidence ratings in the predictive condition did not differ from chance. In addition, a pilot experiment we conducted failed to demonstrate the existence of conscious knowledge at the end of block 2. In light of these results, Experiment 3 had two goals. First, we aimed to ensure that the contextual cuing usually observed in block 3 with similar materials is not a mere short-term memory effect. Second, we aimed to test the hypothesis that the overall contextual cuing observed in block 3 in repeated real-world scenes precedes conscious awareness. To this end, Experiment 3 was similar to Experiment 2, except that the explicit memory task was implemented between block 2 and block 3.

Given results obtained in our lab, we predicted no robust cuing effect in block 2, as well as a weak performance in the target generation task at the end of block 2. However, if a contextual cuing effect nevertheless emerged in block 3, in spite of an interfering task at the end of block 2, this would demonstrate the robustness of contextual cuing in block 3, as well as the primacy of contextual cuing over consciousness.

Method

Twenty undergraduate students participated in Experiment 3. The materials and procedure were the same as in Experiment 2, except that the explicit memory task was implemented after block 2—that is, before block 3. Furthermore, the contrast between the target and the background was increased for one item in the repeated condition and two items in the unrepeated condition because, during the first exposure to those items, several participants failed to find the target within 20 s in both Experiments 1 and 2.

Results and discussion

Search task

As in the previous experiments, trials were excluded from the analysis if the response was not made within 20 s (1.2 % and 0.8 % in the unrepeated and repeated conditions, respectively) and/or was incorrect (0.4 % and 0.2 % in the unrepeated and repeated conditions, respectively). The mean search times are presented in Fig. 3a. A global effect was evaluated with a repeated measures ANOVA conducted with condition (repeated images vs. unrepeated images) and block (1–3) as within-subjects factors. This analysis revealed a significant condition effect, $F(1, 19) = 4.61$, $p < .05$, $\eta^2_{partial} = .20$. No block effect, $F(2, 38) < 1$, $\eta^2_{partial} = .04$, and no condition × block interaction, $F(2, 38) = 2.69$, $p = .081$, $\eta^2_{partial} = .12$, was observed. However, post hoc analyses (Fisher LSD) revealed a reliable facilitating effect in the repeated condition in block 3, $p < .01$, $\eta^2_{partial} = .32$, but not in block 2, $p = .10$, $\eta^2_{partial} = .18$, and not in block 1, $p = .65$, $\eta^2_{partial} = .01$. Thus, as in the pilot experiment and in Experiment 2, the lack of a reliable contextual cuing effect in block 2 suggests that one exposure to repeated scenes is not sufficient to trigger a statistically reliable learning effect in global search performance. More important, however, despite an interfering task at the end of block 2, a large (>800 ms) and reliable ($\eta^2_{partial} = .32$) cuing effect was observed in block 3. Two exposures were therefore sufficient to produce a learning benefit on search performance, demonstrating that the contextual cuing effect observed in block 3 is a long-term, not a short-term, memory effect.

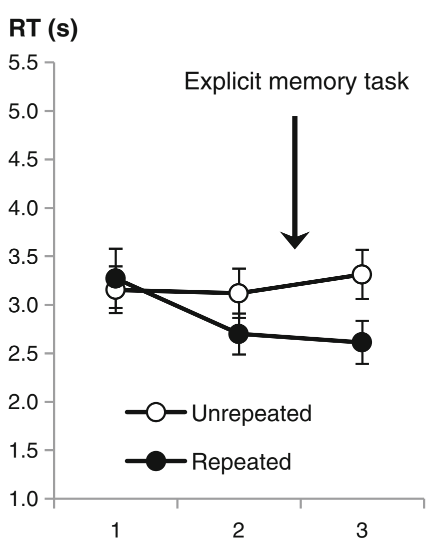


Fig. 3 Mean response times in each block for the unrepeated and repeated conditions used in the global analysis ($N = 20$) (a), for those used in the analysis in the absence of awareness at the end of block 2 (i.e., when the confidence ratings corresponded to random response in the generation task; $N = 18$) (b), and for those used in the analysis in presence of awareness at the end of block 2 (i.e., when the confidence ratings were ≥3 ($N = 18$) (c). The error bars show the standard errors of the means

Target generation task

The averaged placement error and subjective confidence rating obtained in each condition are summarized in Table 1. A one-way repeated ANOVA conducted on each dependant variable yielded a condition effect on the confidence ratings, $F(2, 38) = 33.10$, $p < .001$, $\eta^2_{partial} = .64$, with a significant difference between each condition (for all pairwise comparisons, $p < .05$; Fisher LSD, $\eta^2_{partial} = .76$ for repeated vs. new, $\eta^2_{partial} = .46$ for repeated vs. unrepeated, and $\eta^2_{partial} = .50$ for unrepeated vs. new). However, none of the three conditions differed from each other in the target placement errors, $F < 1$, $\eta^2_{partial} = .05$. The correlation between the target placement errors and the confidence ratings was nevertheless significant in the repeated scenes, $r = -.42$, $p < .001$. The Appendix shows placement errors as a function of the confidence ratings (Panel c), as well as the percentage of responses corresponding to each confidence rating.

A significant contextual cuing effect was thus observed in block 3, while the target placement error in the explicit memory task was not significantly above chance level. This suggests that knowledge related to the context–target-location associations acquired at the end of block 2 was strong enough to facilitate the visual search task in block 3 but did not reach a sufficient level of consciousness to be used in the target generation task. Therefore, a reliable contextual cuing effect preceded reliable awareness of context–target-location associations.

The levels of performance in both the explicit memory task and the search task do nevertheless not represent a clear-cut picture. Panel c in the Appendix summarizes the cuing effects and the target placement errors as a function of the confidence ratings in the target generation task.

First, although the average target placement errors did not differ significantly from chance, the average confidence ratings were significantly higher in the predictive condition than in the unrepeated and new conditions, suggesting that participants had nevertheless consciously detected some aspects of the regularities by the end of block 2. Nonetheless, the use of confidence ratings as a reliable measure of knowledge related to the context–target-location associations is controversial.[2] Indeed, even when participants chose 2 or 3 (*not confident* and *low confidence*) in the repeated condition, the averaged placement error (341 and 320 pixels, respectively) did not differ significantly from the average placement error in the new condition (361 pixels), $t(41) < 1$ and $t(25) < 1$. One interpretation is that, in contrast to a cautious strategy (i.e., application of a fairly high criterion for making a judgment greater than 1), participants used the whole scale and/or based their feeling of confidence on the recognition of the scene and/or their fluency in the search task instead of the target location.

[2] Note that the control group in Experiment 2 showed that familiarity with repeated images is not sufficient to trigger a contextual cuing effect.

As a result, they mainly tended to *overestimate* their confidence in their target placement, particularly in the present experiment—that is, when knowledge was the weakest. The pattern of performance in the unrepeated condition supports this hypothesis. Although the participants had reported a confidence rating ≥2 in 51 % of the unrepeated trials, only the average target placement error associated with a confidence rating of 5 (which corresponded to 3 % of all given responses in the unrepeated condition) was above chance level. Moreover, when the analysis of search times was limited to the scenes that triggered a confidence rating of ≥4 in the repeated condition (which concerned 14/20 participants), a reliable contextual cuing effect was observed in block 2 (701 ms; $p < .001$, $\eta^2_{partial} = .62$)—that is, before the implementation of the explicit memory task. Thus, even in this marginal case suggesting the presence of a small amount of explicit knowledge at the end of block 2, it is possible that contextual cuing preceded consciousness. In other words, it might be that implicit learning produced a contextual cuing effect in block 2, which then produced explicit awareness.

The second controversial aspect of the present experiment concerned the marginally lower target placement error in the repeated condition than in the scenes never seen before. Indeed, the detailed results for each item suggest awareness for several context–target-location associations at the end of block 2 (see the Appendix, Panel c). However, contrary to the strong cuing effect observed in block 3, the reliability of awareness remained too weak to have a substantial impact on the overall target placement error in the generation task. The large effect size observed in the explicit memory task in Experiment 1 ($\eta^2_{partial} = .85$)—that is, when knowledge was mostly explicit—shows that the weakness of the effect in the present experiment ($\eta^2_{partial} = .05$) is due to the weakness of awareness, and not to a problem of sensitivity of the measure to condition effects due to high variability.

In conclusion, although we cannot firmly exclude the possibility that conscious awareness of context–target-location associations preceded contextual cuing for a few items, contextual cuing preceded conscious awareness for most items. If participants acquired some explicit knowledge at the end of block 2, this did not reach a sufficient level of consciousness to be effectively used in the target generation task. In contrast, knowledge acquired in block 2 strongly facilitated the search task.

General discussion

The present study examined how the conscious or unconscious nature of knowledge acquired during the analysis of visual real-world scenes evolves across multiple exposures to repeated images. More specifically, we tested the hypothesis that even when knowledge related to statistical contingencies eventually becomes fully accessible to conscious awareness after extensive training, incidental learning tends to first give rise to unconscious knowledge. To this end, we used the contextual cuing paradigm, which empirically reveals either conscious or unconscious knowledge, depending on the testing environment (Brockmole & Henderson, 2006a; Chun & Jiang, 1998, 2003).

In line with previous work (Brockmole & Henderson, 2006a; Goujon et al., 2012), this study demonstrated that, after an extensive training of searching a target embedded within repeated real-world scenes, knowledge related to associations between scenes and a target location was mostly accessible to explicit awareness (Experiment 1). Even after only three exposures to the regularities, an objective measure of consciousness (i.e., a target generation task) revealed the existence of some explicit knowledge (Experiment 2). However, contextual cuing effects were observed even with random responses in the explicit memory task and, therefore, in the absence of awareness. More important, despite robust and strong contextual cuing effects in block 3 (i.e., a benefit of >800 ms in Experiment 3), a direct memory task failed to provide significant evidence of global explicit knowledge related to the context–target-location associations just prior to that block (i.e., the target placement error in the generation task was not above chance level at the end of block 2). This finding demonstrates that even when some statistical contingencies begin to be explicitly detected early during the task and become fully accessible to conscious awareness after extensive training, learning and the use of regularities tend to first take place at an unconscious level.

Conscious awareness therefore does not appear to account for the early cuing effect observed in real-world scenes. As a whole, the pattern of results obtained in the explicit memory task after two or three blocks of searching within real-world scenes closely resembles what is usually observed after a session of the typical implicit learning tasks, presenting conspicuous regularities embedded within arbitrary materials, such as the classical procedure of *contextual cuing* (e.g., Smyth & Shanks, 2008) or the procedure of *serial reaction time* (e.g., Destrebecqz & Cleeremans, 2001; Runger et al., 2009). Although knowledge acquired during the analysis of visual scenes may strongly facilitate visual search before being significantly usable in a direct memory task (Experiment 3), Experiment 2 shows that, early during statistical contingency acquisition, both implicit and explicit knowledge coexist in memory. However, contrary to typical implicit learning tasks, awareness related to the context–target-location associations increased throughout the course of repeated exposures. At a descriptive level, contextual cuing effects were generally stronger when they were associated with awareness in the first stage of learning (see the Appendix). Consciousness might modify the nature of representations regarding the regular structures present in the materials and might enhance the consolidation of these structures in memory (for a similar argument, see Goujon, 2011; Goujon et al., 2012).

The primacy of contextual cuing effects over conscious awareness of regularities raises the question of whether implicit and explicit knowledge are supported by common or independent learning systems. This issue has been the subject of many discussions in the field of implicit learning and memory (e.g., Reber & Squire, 1998; Roediger & McDermott, 1993; Rünger et al., 2009; Schacter & Tulving, 1994; Shanks & Berry, 2012; Shanks et al., 2003). Arguments in favor of a multiple-systems view often come from dissociations between direct and indirect measures of memory. In contrast, correlations between those measures have been interpreted to suggest a single declarative source of knowledge (Shanks & Perruchet, 2002; Shanks et al., 2003). However, the logic of dissociation remains controversial, and numerous critiques and confusions call into question its validity (for a review, see Rünger et al., 2009; Shanks & Berry, 2012). Dissociation may reveal the existence of multiple learning systems and the formation of different sources of knowledge (conscious or unconscious) during learning. But it may also reveal that divergent retrieval processes in memory have different impacts on performance, whereas a single and same source of knowledge underlies performance in both tasks (for a review, see Shanks & Berry, 2012). Thus, in spite of the presence of vivid awareness of regularities at the end of block 17, the correlation between direct and indirect measures was weak (−.29). It is probable that even though direct and indirect measures reveal a single source of knowledge, access to and expression of this knowledge differ depending on the test and other components. Thus, we suggest that the weak degree of correspondence between both measures in the first stages of training remains compatible with a model according to which unconscious and conscious knowledge acquired during the search task emerge from common learning systems. A single memory trace might be created by repeated exposures to a scene, and this single trace would form the basis of responses in both types of test (Shanks & Berry, 2012).

In agreement with alternatives to a dichotomous view of conscious and unconscious processes (e.g., Cleeremans & Jiménez, 2002; Norman, 2010), a feasible sketch would be that, during the analysis of scenes, fragments of attended stimuli are spontaneously extracted without intention to learn (Chun & Jiang, 1998; Fiser & Aslin, 2001). This automatic extraction occurring during an unsupervised procedure would inherently result in a trace in memory integrating fragments of multimodal information processed within a short spatiotemporal window. In the early stage of development or skill acquisition, the weakness and instability of connections binding contingent structures would not allow the observer to activate a coherent representation of past stimuli and, consequently, knowledge related to the regular structures might remain inaccessible to awareness. This trace would nevertheless be capable of influencing further processing and behavior during subsequent exposures to the stimulus through mere associative priming mechanisms, which would be relatively inflexible. During repeated or prolonged exposures to similar exemplars, the accumulation of details within the trace in memory and the reinforcement of connections would progressively increase the quality of representation resulting from the activation of this trace and, thereby, would favor the explicit detection of regularities. The gradual emergence of regular structures in consciousness would reach intermediate states before being more and more effectively usable in direct memory tasks. Consciousness would then modify the weight of connections and, more important, would confer to knowledge the flexibility required to be used in different tasks and situations. Such a general iterative process of redescription of implicit knowledge into explicit knowledge is a common conception in the developmental area (Karmiloff-Smith, 1992).

As such, dissociation between direct and indirect measures of acquired knowledge may merely reflect the fact that different tasks involve different mechanisms of retrieval, rather than different sources of knowledge. One hypothesis is that unconscious knowledge acquired during a visual task can be retrieved only in this context. In agreement with this hypothesis, Jiang and Song (2005) showed that spatial layouts acquired implicitly in a visual search task were not expressed in a different visual task (i.e., a change detection task), suggesting that the content of learning is, in part, task specific. Learning revealed by implicit contextual cuing effects might be linked with archaic conditioning between a stimulus (i.e., repeated image) and a behavioral response (i.e., eye movement). In agreement, Goujon and Fagot (2013) recently showed that typical contextual cuing effects emerge in baboons earlier than in humans.

The automaticity of contextual cuing mechanisms is supported by a result reported by Brockmole and Henderson (2006b). When repeated real-world scenes and the target location were unexpectedly mirror reversed during a transfer phase, the eyes initially moved toward the target position in the previous presentation of the display and not toward the object on which the target used to appear. Only afterward were the eyes directed to the target's new position. This surprising result demonstrates how a repeated scene is associated with a behavioral response (eye movement) and how attention is automatically guided by the context during the search task. Nonetheless, conscious awareness of regularities might result in cognitive flexibility by permitting for adjustments, if required, or by expression of knowledge in different tasks. Furthermore, we also suggest that the striking differences in the strength of the contextual cuing depending of the testing environments are related to the presence or to the absence of conscious awareness of regularities. As such, conscious awareness of regularities would enhance their consolidation and retrieval in memory but would also favor deployment of attention toward the target location (for a similar argument, see Goujon et al., 2012; Kunar et al., 2006).

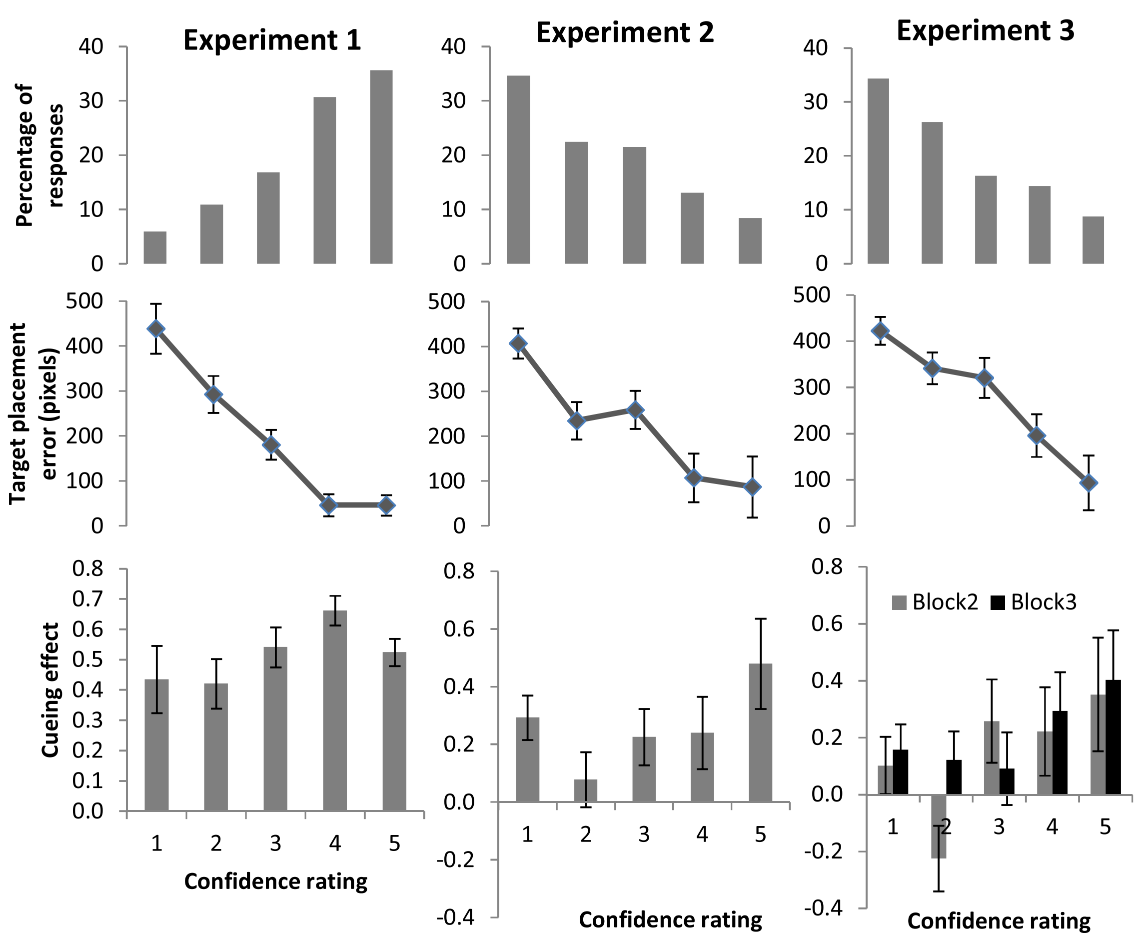
To conclude, the present study supports a graded view of consciousness. However, the view according to which explicit detection of regularities is independent of unconscious knowledge already in memory remains plausible as well. Implicit and explicit knowledge might develop independently of one another (e.g., Willingham & Goedert-Eschmann, 1999). Instead of being the consequence of the degree of knowledge, explicit detection of regularities could be the consequence of the degree of attention allocated to the stimuli. From this perspective, our results suggest that the explicit detection of regularities occurred earlier in the scenes that gave rise to a priori longer RTs at the beginning of training and, thus, received deeper attentional processing. Although our results demonstrate that, in the early stage of incidental learning, acquisition of implicit knowledge tends to precede explicit detection of regularities, further studies are required to more firmly establish the causal relationships between consciousness and learning and the possibility that explicit detection of regularities is enhanced by implicit knowledge already in memory from previous experience.

Acknowledgments We would like to thank Eric Ruthruff and two anonymous reviewers for their feedback on the manuscript.

Appendix

Percentage of responses, averaged target placement error, and contextual cuing effect as a function of the confidence ratings (1–5) observed at block 17 in Experiment 1 (panel a), at block 3 in Experiment 2 (panel b), and at blocks 2 and 3 in Experiment 3 (panel c).

The cuing effect is a proportional measure of performance where the difference in search time between the unrepeated and repeated trials was divided by the search time observed for unrepeated trials (see Brockmole et al., 2008; Goujon et al., 2012). Using this procedure, for example, a cuing effect of .33 would indicate that search performance for repeated trials was one-third faster than unrepeated trials. In each experiment, an averaged search time in the unrepeated condition was calculated for each participant with the eight trials of the block presented in the figure. Both average cuing effects and target placement errors for each confidence rating were calculated from all data points of the repeated condition, and not from a participant's score. Thus, the standard errors of the means represented the variance in all the data points.



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