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Acquisition of Procedural Knowledge about a Pattern of Stimuli That Cannot be Articulated

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This research demonstrates a process of nonconscious acquisition of information about a pattern of stimuli and the facilitating influence of this knowledge on subjects' subsequent performance. Subjects were exposed to a sequence of frames containing a target, and their task was to search for the target in each frame. The sequence of target locations followed a complex pattern. The specific sample of subjects was selected to ensure that they would be sufficiently motivated and that they would have appropriate analytical and verbal skills to report whatever they experienced while participating in the task: All subjects were faculty members of a psychology department. Extensive postexperimental interviews with subjects indicated that none of them noticed anything even remotely similar to the actual nature of the manipulation (i.e., the pattern). However, the accuracy and latency of their responses indicated that, in fact, they had acquired a specific working knowledge about the pattern, and that this knowledge facilitated their performance. The results demonstrate that nonconsciously acquired knowledge can automatically be utilized to facilitate performance, without requiring conscious awareness or control over this knowledge. This phenomenon is discussed as a ubiquitous process involved in the development of both elementary and high-level cognitive skills.

It has recently been argued that learning various kinds of basic cognitive and procedural knowledge involves acquisition of complex processing algorithms of which the subject is not aware (Lewicki, 1985, 1986a, 1986b; Lewicki, Czyzewska, & Hoffman, 1987). In other words, the subject acquires some form of "working knowledge" about patterns of stimuli and how to process them, although the subject is unable to articulate these processing algorithms. For example, most people are unable to articulate semantic and syntactic rules of the language they use, although at the same time, there is no doubt that they have a working knowledge of those rules (e.g., when asked by a foreigner, native English speakers can usually say *which one* of two phrases or sentences is cor-

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rect, but usually they cannot say *why;* all they can say is that the correct one "sounds better," Lewicki, 1986a).[1] The same is true about elementary perceptual phenomena. For example, most people have no idea how they go about determining distances between objects in three-dimensional space, although everybody possesses the necessary (inferential) processing algorithms to accomplish this task "automatically" (Hochberg, 1978; Kaufman, 1974).

The role of procedural knowledge that is not accessible to conscious awareness is also evident in social cognition. For example, very few people are capable of articulating any of the algorithms that they use to determine whether a human face is attractive, although everybody has such working algorithms delivering output automatically and instantaneously. People are unable to articulate even the most basic proportions of the human face, but they possess working knowledge of these proportions. It has been shown that people are sensitive to even small violations of the proportions, and in such cases they instantly have a "feeling" that something is wrong (Lewicki, 1986a). In one study, subjects were exposed to a set of schematic sketches of human faces, some of which slightly violated one of the proportions. It appeared that most subjects had no difficulty with correctly pointing out the "less realistic" faces, but none of them were able to specify how exactly they arrived at their judgment.

A number of studies have suggested that subjects are able to acquire specific working knowledge (i.e., processing algorithms) not only without being able to articulate what they had learned, but even without being aware that they had learned anything (Lewicki, 1986a, 1986b; Lewicki & Hill, in press). In the learning phase of those studies subjects were exposed to stimulus material that consistently followed some pattern. The pattern was not salient, and the subjects were unable to detect it even when they were explicitly asked and motivated to do so. In the testing phase, subjects performed a task that was relevant to the pattern. It appeared that, although subjects were unable to articulate the pattern manipulated in the learning phase stimulus material, they still had acquired some working knowledge about it, since their performance in the testing phase showed a response bias that was consistent with the pattern.

The response bias observed in those studies was hypothesized to reflect a kind of nonconscious priming effect, where the knowledge about the pattern primed specific responses (i.e., those consistent with the pat-

[1] This area is relevant to the research on "implicit learning of artificial grammars" (Reber, 1976; Reber & Allen, 1978). For the recent discussion on implicit learning, see Dulany, Carlston, and Dewey, 1984; Reber, Allen, and Regan, 1985; and Dulany, Carlston, and Dewey, 1985.

tern). If the testing phase stimulus material was consistent with the pattern, then the priming facilitated subjects' performance in the testing phase, that is, it decreased response latency and increased accuracy. However, if the testing phase material was inconsistent with the learned pattern, then the priming was found to interfere with the task—the wrong responses were primed.

A major issue of concern in this research is the relation between nonconsciously acquired processing algorithms and consciously controlled knowledge. Past research has addressed this issue in postexperimental interviews during which subjects were asked, more or less directly, about the crucial aspects of the manipulation and about their current declarative knowledge relevant to what was learned nonconsciously. The convergent evidence obtained from those tests indicates that subjects were not aware of the knowledge that they had been using during the testing phase of the experiments, and that they could not reconstruct this knowledge even when they were asked very specific questions.

A possible confounding factor that might have contributed to those negative results is subjects' lack of ability to articulate their introspective experiences. In most of these experiments the manipulated pattern of the material was simple enough to be articulable by all subjects (had they only noticed it). However, it can still be argued that if the subjects were more "sophisticated" and used to reporting introspective experiences, they would either tell us something that would suggest their partial awareness of what was learned (i.e., the rule that led them to respond consistent with experimental manipulations), or they would report something else that might clarify the nature of this process.

The current experiment was designed to explore the introspective experiences that subjects have when acquiring cognitive skills without awareness. Therefore, the specific sample of subjects who participated in this experiment was selected to ensure that they have sufficient verbal and analytical skills to articulate whatever they experienced, and that they would be cooperative and motivated to report whatever they noticed or felt. The subjects were all faculty members of a university department of psychology.

METHOD

Overview

Subjects were exposed to a long sequence of frames presented on the computer screen. Each frame consisted of a target character exposed in one of four possible locations on the screen. The subject's task was to locate the target and then press a button corresponding to its location. The entire sequence of locations of the target followed one consistent, but complex and nonsalient, pattern, and subjects were expected to acquire nonconsciously the working knowledge about this pattern. In other words, the gradual increase of subjects'

performance (decrease of response latency) over the entire sequence of trials was expected to be due not only to the effect of unspecific training, but also to the acquired processing algorithm for "predicting" subsequent locations of the target (according to the pattern) and the priming of appropriate responses. To test this expectation, the specific pattern of the stimulus material was designed so that some of the trials of the sequence could be predicted based on the pattern while others could not. It was expected that if subjects acquired the working knowledge about the pattern, their performance on the predictable trials would be better than on the unpredictable ones. In addition, the pattern was changed near the end of the sequence of trials. Subjects' performance was expected to deteriorate after the change because their working knowledge about the pattern was of no further utility. This decrease, however, was expected to pertain exclusively to those trials that used to be predictable from the pattern.

Subjects

Subjects were 9 faculty members from the department of psychology at The University of Tulsa, aged 29–52. It was intended to test all 12 members of the faculty; however, 3 of them were not available when the experiment was conducted (they were on leave, out of town, etc.). All 9 subjects hold a Ph.D. degree in psychology, and all of them are at least somewhat familiar with cognitive psychology. At the point of participating in the experiment, subjects knew that the authors of this study investigate nonconscious processing of information.

Procedure

Subjects were tested in a familiar environment: Six persons were tested in their own offices using the computers they usually use, and three others were tested in their colleagues' offices. The computers were all IBM-PC's with Amdek 310A monitors. All instructions were displayed on the screen. Subjects were asked to react to the appearance of the target (letter *X*) by pressing one of four keys corresponding to the locations of the target. The screen was divided by one vertical and one horizontal solid line into four quadrants of equal size (see Fig. 1).

The target could appear in any of the quadrants, but there was only one possible location of the target in each quadrant (5 cm distant from the crossing of the lines dividing the screen). The keys used to respond to the target were 4, 5, 1, and 2 on the numeric keypad, which form a 2 × 2 square corresponding to the four quadrants of the frame. Subjects were asked to fix their sight on the intersection of the lines. This allowed them to see the target without moving their eyes. Both speed and accuracy were stressed in the instructions, and subjects were informed that both would be recorded by the computer.

Subjects were told that the experimental session would be long (about 45 min) and that the task would be boring. They were also told that the experimenters did not want to mislead them and that, therefore, the specific purpose of the experiment would not be disclosed until the postexperimental debriefing.

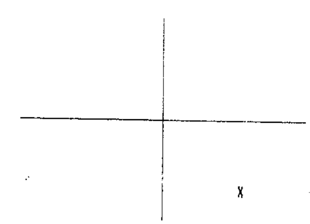

FIG. 1. One of four frames exposed to the subjects.

After the session, subjects were extensively interviewed about their subjective experiences (while performing the task) and any observations about the task. They were asked specifically about any patterns of the stimulus material they had noticed and about any changes in their performance that they subjectively experienced over the segments. The interview required between 25 and 40 min and was informal, except for the crucial questions which were worded in the same way in each interview (the questions are quoted in the Results section).

Stimulus Material

Manipulated pattern. There was a total of 4080 exposures. The sequence of target locations consisted of logical blocks of 5 exposures each. Twelve different blocks were designed and up to the point when the pattern was changed, the sequence of exposures consisted exclusively of those 12 blocks presented in random order. The crucial change of the stimulus pattern was introduced in the last one-ninth of the entire sequence of trials. It involved a switch to a second, different set of 12 blocks. There were two orders of presentation of the stimulus material (beginning with the first or beginning with the second set). Four subjects were exposed to the stimulus material arranged in the first order, five subjects were exposed to the stimulus material arranged in the second order. (The order of presentation did not affect any of the dependent measures.)

The following rules applied to both sets of blocks. Three out of the 12 blocks of exposures started in each of four quadrants (there were three blocks that began with the target displayed in the upper left quadrant, three in upper right, etc.). The second exposure of each block was never in the same quadrant as the first one, that is, the target was located in one of the three remaining locations. Thus, the target could "move" (relative to the first trial of the block) horizontally (i.e., left or right), vertically (i.e., up or down), or diagonally. The third location was determined based on whether the movement of the target from the first to the second trial was horizontal, vertical, or diagonal. For example, if it was horizontal, then the next was vertical, if it was vertical, then the next was a diagonal, and if it was a diagonal, then the next was horizontal. The following target locations (i.e., those in the fourth and the fifth trial) were designed according to analogous rules, that is they depended on the preceding two locations of the target. The target was never displayed in the same location twice in a row and it "returned" to the same location only after being displayed in at least two other locations (i.e., it never "moved" back and forth between two quadrants).

The sequence of blocks was random, with the limitation (necessary to follow the rule) that the target was never displayed twice in a row in the same location.

The crucial change in the pattern (in the last one-ninth of the sequence) did not affect the general rules according to which the blocks were designed (the target was never displayed twice in the same location, it never "returned" to the same location after being displayed in less than two other locations, etc.). Also, the first two locations of each of 12 blocks were the same in both sets of blocks. However, the rules relating the location of the target in the third, fourth, and fifth exposure to the preceding two locations were "reordered." Namely, the specific rule that was used in the first set of 12 blocks to determine the third location of the target (based on the first and second one), was used in the second set of 12 blocks to determine the fifth location (based on the third and fourth one); the rule which determined the fourth location in the first set, was used in the second set to determine the third location; and the rule used to determine the fifth location was used to determine the fourth one.

This way of designing the stimulus material ensured not only an overall high degree of similarity between the two sets of blocks, but also, that both of them would involve the same number of locations in each quadrant and the same rules relating a location of a target and two preceding locations. The only difference between the two sets pertained to the order in which the rules were applied. Therefore, it can be assumed that these two sets of blocks involved using the same combinations of muscles for moving the fingers to depress the appropriate keys. Thus, after the switch of the pattern, any changes in subjects' performance cannot be attributed to the operation of muscle training or muscle fatigue factors.

This arrangement of the stimulus material also allowed to test whether the effect of the manipulation was specific, that is, that it only affected Trials 4–5 as was hypothesized. Namely, because the order of blocks was randomized, subjects could not acquire any knowledge that would allow them to predict the target location on the first trial. Also, the second trial was always completely unpredictable because the target on the second trial could appear with equal probability in any of the three other quadrants. Thus, each block consisted of two trials that were completely unpredictable (i.e., the first and second trial) and three trials that were perfectly predictable from the rules of the set (i.e., the third through the fifth trial). If the gradual improvement of subjects' performance over the sequence of trials reflected not only the effect of unspecific training but also the effect of priming of correct responses due to acquisition of working knowledge about the pattern, then subjects' performance on the third, fourth, and fifth trial should improve faster and should be better overall than the performance on the first and second trial. Also, if the predicted decrease of subjects' performance (expected after the change of the pattern) reflected the fact that the working knowledge about the pattern was no longer useful, then the decrease should be most evident in subjects' performance on the third through fifth trial rather than on the first and second trial.

Sequence of exposures. The stimulus material was divided into 17 segments of 240 trials each. The segments were separated by 10-s long breaks, during which the subjects were encouraged to relax. Each segment consisted of 48 blocks of five trials each. Within each block the sequences of target locations followed the manipulated pattern. The sequence of blocks was random. The exposures of the target were accompanied by simultaneously generated sounds designed to help the subject identify the beginning and end of each block, thereby facilitating the processing of the material in terms of chunks of five trials. A sequence of five notes (tuning note A, G, F, E, and D; duration .10 s) accompanied the five trials in each block.

The pattern of stimulus material was changed after 15 segments. The final two segments followed a new pattern.

RESULTS

Performance in the Search Task

The means of response latencies in each of the 17 segments are displayed in Fig. 2. Subjects' performance considerably improved over the segments, probably to a large extent due to unspecific training. Consistent with expectations, response latency clearly increased after the change in the pattern (i.e., in the 16th segment), suggesting that subjects acquired some working knowledge about the pattern of stimuli during the first 15 segments of the stimulus material and that their performance in those 15 segments was at least partially due to using this knowledge. The difference between response latency in the crucial 16th segment and the preceding (15th) segment is significant, $t(8) = 4.01$, $p < .004$, and it is the only reliable increase in response latency over the 17 segments.

The effect is even more pronounced when the number of responses that were both very fast and accurate were compared across the seg-

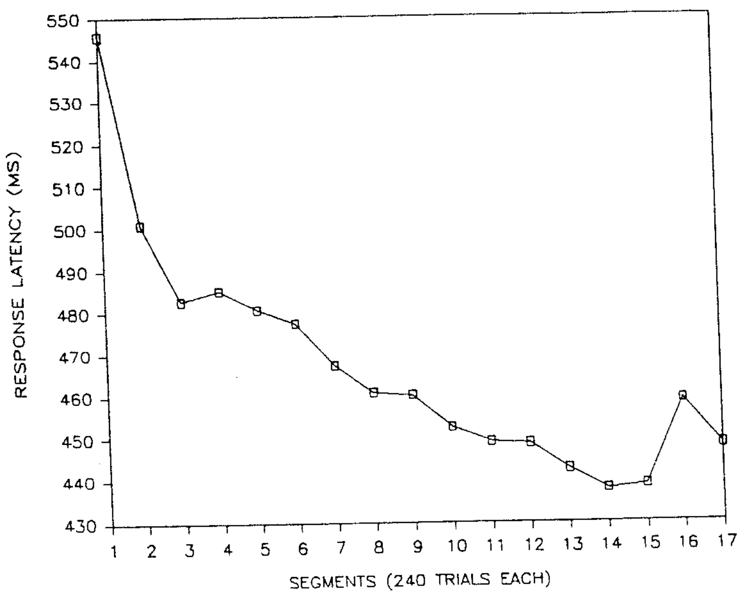

FIG. 2. Means of response latency in 17 segments of the task.

ments. This index represents the effect of priming of correct responses (it may reflect the number of successful "guesses"). The average number of accurate responses (computed for each segment) faster than 400 ms are displayed in Fig. 3. The only significant decrease of the number of responses that met those criteria was found in the crucial (16th) segment, $t(8) = 6.32, p < .001$.

The pattern of the stimulus material and the change introduced in the 16th segment were irrelevant to the first two trials of each block. Only performance on the third, fourth, and fifth trial of each block could benefit from the acquisition of working knowledge about the pattern and only those trials could be affected by the pattern change (due to the sudden futility of this knowledge). The average number of fast and accurate responses computed separately for the first two and the subsequent three trials in each segment is displayed in Fig. 4.

Consistent with expectations, subjects' performance on Trials 3–5 was initially at the same level as their performance on the first two trials (see Fig. 4, Segments 1, 2, and 3). However, it increased faster, it was better overall, and when the pattern was changed in the 16th segment it was more affected by the change (i.e., decreased more). This pattern of results is consistent with the notion that the superiority of subjects' performance on Trials 3–5 (over Trials 1 and 2) is due to the development and operation of working knowledge about the pattern, since when the

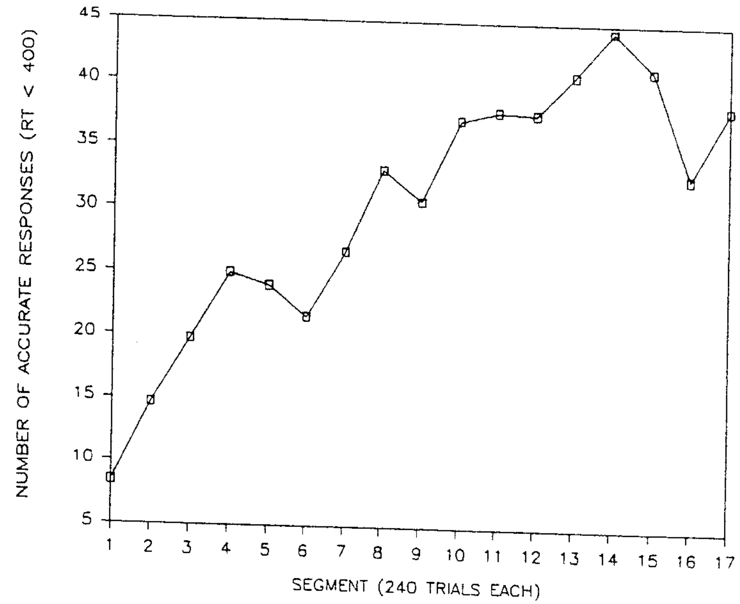

FIG. 3. Number of fast (RT < 400 ms) and accurate responses in 17 segments of the task.

knowledge became useless in Segment 16, subjects' performance on Trials 3–5 dropped to the level of their performance on Trials 1 and 2. These results are reliable as shown by means of a 2 × 17 (Trial [1–2 vs 3–5] × segment) analysis of variance with repeated measures on both factors. There was a significant effect of trial, $F(1,8) = 12.91$, $MS_e = 229.50$, $p < .0072$, indicating that subjects gave relatively[2] more fast and accurate responses in Trials 3–5 as compared to Trials 1 and 2. There was also a significant interaction of trial and segment, $F(16,128) = 3.45$, $MS_e = 17.31$, $p < .0001$, indicating that the dynamics of changes in subjects' performance over the segments was different for the first two and the subsequent three trials of each block. This interaction seems to be due to two factors.

First, the effect of the change of pattern in the 16th segment was, as expected, more pronounced for the last three than for the first two trials of each block. A planned comparison revealed a reliable partial interaction between trial (1–2 vs 3–5) and segment (15 vs 16), $F(1,8) = 10.54$, $MS_e = 12.43$, $p < .011$. This interaction was due to a strong decrease in performance on Trials 3–5, $F(1,8) = 25.11$, $MS_e = 15.86$, $p < .0014$, and

[2] The index of the number of fast and accurate responses computed for Trials 3–5 was based on three trials and, therefore, it was weighted by two-thirds to achieve its compatibility within the analogous index for Trials 1 and 2.

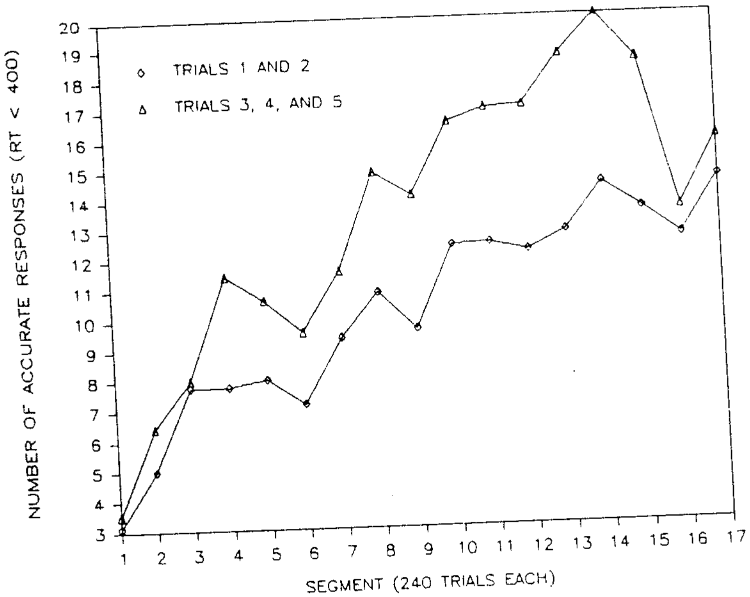

FIG. 4. Number of fast (RT < 400 ms) and accurate responses in 17 segments of the task, separately for the predictable trials (1 and 2), and the unpredictable trials (3–5). (The index of the number of fast and accurate responses computed for Trials 3–5 was based on three trials and, therefore, it was weighted by two-thirds to achieve its compatibility with the analogous index for Trials 1 and 2).

the lack of a reliable effect on Trials 1 and 2, $F(1,8) = 0.64$, $MS_e = 22.35$, ns.

The second (independent) source of the interaction between trial and segment was that the difference between subjects' performance on the first two and the last three trials gradually increased over the segments (up to the point when the pattern was changed). The two curves start from the same point and have similar shape, however, the one representing Trials 3–5 is systematically steeper than the one representing Trials 1 and 2 (see Fig. 4). This was confirmed by the reliable partial interaction between trial and segment obtained in planned comparison in which the two last segments (those affected by the change of the pattern) were excluded, $F(14,112) = 3.87$, $MS_e = 14.60$, $p < .0001$, and in the additional planned comparison in which the first seven segments were contrasted with the next seven, yielding a reliable interaction (2 × 2) between trial and segment (1–7 vs 8–14), $F(1,8) = 12.15$, $MS_e = 46.91$, $p < .0083$.

Postexperimental Interviews

The subjects seemed tired after the session, but they were still excited and anxious to learn about the exact nature of the experiment. It was the interviewer's impression that subjects attempted to detect a manipulation and its meaning, although only two subjects admitted that they tried to do it.

The first question of the interview pertained to whether the subjects noticed "anything special about the stimulus material." All 9 subjects reported that the task was very demanding and that they felt tired. They also offered various comments and associations unrelated to the manipulated pattern. Four subjects said they suspected that they were exposed to subliminal stimuli, but they could not describe them. (This suspicion was probably due to the fact that subjects knew that the experimenters investigate nonconscious processing). Because none of the subjects mentioned anything that even came close to the crucial sequence of trials, they were additionally encouraged to say whatever "suspicions" they might have about the stimulus material. Finally, they were asked directly whether they "noticed anything about the sequence of locations of the target." In response, subjects thought about the question for a while trying to recall the sequence; three subjects recalled that the target had never appeared twice in a row in the same quadrant, and one subject noticed that the target never moved clockwise four times or four times counterclockwise (which was true). Again, none of the subjects mentioned anything even close to the manipulated pattern of exposures.

The second topic of the interview referred to the self-perceived changes in subjects' performance. Subjects were asked whether they "perceived the level of [their] performance as stable or whether it changed over time." All 9 subjects reported that they felt that they made progress and that after some time the task became "easier." Four subjects said that at some point "their fingers were doing the job by themselves," relatively independent of the level of subjects' concentration on the task. However, all subjects except one reported that they also experienced some decrease in performance in one of the last segments. Three subjects used the expression that they "suddenly lost the rhythm." Two of the subjects who suspected subliminal exposures said they had a suspicion that the decrease in their performance was due to some interfering effects of messages to which they were subliminally exposed.

DISCUSSION

The results demonstrate the process of acquisition of procedural knowledge about a pattern of stimuli. The process was nonconscious in the sense that subjects were neither aware that they were learning anything nor were they aware of how the acquired knowledge facilitated their performance. The analysis of the number of fast and accurate responses suggests that the influence of the knowledge about the pattern on subjects' performance was mediated through a process of priming of responses consistent with the pattern. The data indicate that after being exposed to about 150 blocks of the stimulus material (see Fig. 4), subjects acquired knowledge about the pattern. However, this knowledge had a different status than what people usually refer to when they say that they know something. The knowledge they acquired in this experiment was clearly used by subjects, that is, it facilitated subsequent cognitive processes, but unlike other knowledge, it was stored in a way that made it inaccessible for conscious control or even examination.

The specific influence of the knowledge on subjects' performance was automatic in the sense that it was not mediated by consciously controlled processes. However, it was different from automatic processes studied before (e.g., Shiffrin & Schneider, 1977), which involved utilization of knowledge that was at one time consciously controlled and only later, due to extensive training, gradually became automatic. The knowledge observed in this experiment was found to influence specifically subjects' performance without ever being consciously articulated, recognized, or controlled. This was clearly evident in the results of the postexperimental interviews with these highly competent subjects.

Although the results demonstrate the process of acquisition of knowledge, they do not allow one to say precisely what kind of knowledge was acquired. At least two possibilities can be considered here. Subjects could have either learned the specific set of rules used to generate the sequences of target locations, or they could have learned the set of 12 concrete blocks (i.e., sequences) used in the learning phase of the material. These two possibilities involve different cognitive processes (e.g., the former assumes some process of generalization), however, in functional terms they may potentially lead to very similar outcomes. There is evidence indicating that memory representations of concrete instances may influence subsequent encoding of stimuli that are not identical but only "similar" to these concrete instances (Gordon & Holyoak, 1983; Lewicki, 1985).

For this reason, an empirical discrimination between these two interpretations appears difficult. For example, subjects in the current experiment might, in fact, have learned only concrete instances, but this knowledge may still generalize to a new, similar instance if one is encountered (Gordon & Holyoak, 1983; Lewicki, 1985; see also Smith & Medin, 1981, for a discussion of this issue in the context of models of semantic memory).

Subjects in this experiment were found to have very little choice or influence over whether or not they learned the pattern and, after they acquired some knowledge, whether or not to use this knowledge. This seems to be an important feature of the observed phenomenon. It appears

that the human cognitive system is capable of memorizing more information about encountered stimuli than can be processed through consciously controlled channels. Moreover, some of this involuntarily processed and memorized information is capable of specifically influencing subsequent cognitive processes, again independent of subjects' will and knowledge. The processes observed in this study illustrate a general property of human information processing, due to which some aspects of nonconsciously acquired information are automatically utilized and begin to generate respective priming effects when relevant stimuli are encountered. This property of the cognitive system allows a person to acquire and take advantage of much more information than can be handled by the (relatively limited) consciously controlled channels. It also releases the consciously controlled processing mechanisms from the numerous supporting tasks required for every act of consciously controlled cognition, like recognition of shapes and locations of objects in three-dimensional space (Hochberg, 1978), verbalization and speech production (Lewicki, 1986a), or the generation of first impressions of social stimuli (Nisbett & Wilson, 1977).

It seems that various aspects of human knowledge are acquired through processes similar to those observed in the present experiment, and using this knowledge is not only independent from perceivers' consciously controlled decisions but the perceivers even lack the ability to articulate the knowledge they use (Lewicki, 1985, 1986a, 1986b). This nonconscious acquisition of knowledge increases the overall processing capability of the human cognitive system. However, it may be speculated that it also involves the risk of acquiring and developing working knowledge that is inconsistent with consciously controlled feelings, values, or preferences. Some common observations suggest a clear inconsistency between some of those inaccessible processing algorithms and consciously accessible knowledge. For example, some social stimuli are automatically categorized as "moving," and, despite the fact that this may be inconsistent with what the person thinks on the consciously controlled level, the processing algorithms responsible for generating those categorizations may automatically trigger respective behavioral reactions (e.g., tears). People usually cannot control this kind of reaction. Sometimes they are even surprised and wonder why they have responded this way, because they consciously classify the situation as unrealistic, naive, or melodramatic. For example, when watching movies like *Love Story* or *Lassie Come Home* people often recognize the primitive manipulation designed to affect viewers' feelings, but they still feel touched.

This independence of acquisition of some processing (e.g., categorization) algorithms from consciously controlled knowledge may be responsible for the development of algorithms that are disfunctional and may cause psychological disorders. It has been recently suggested that due to this independence from conscious control, some processing algorithms may produce encoding biases that may result in idiosyncratic interpretations of stimuli as supportive of preexisting cognitive biases, although no objective evidence is present (Lewicki, 1986a; Lewicki & Hill, in press). Thus, such processing algorithms would be self-perpetuating.

In summary, the results of the present experiment demonstrate a nonconscious process of acquisition of information and its specific facilitating influence on subsequent performance. This phenomenon implies that nonconsciously acquired knowledge is automatically put to work, and that the utilization of certain information may be independent of conscious control over or awareness of this information. These conclusions are at odds with most common views of human information processing; however, the analysis of various aspects of human cognitive development (Hochberg, 1978; Kihlstrom, 1984; Lewicki, 1986a; Lewicki & Hill, in press) seems to imply that there is no other way to explain the acquisition of both elementary and high-level cognitive skills.

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