Implicit Learning

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Abstract

Implicit learning appears to be a fundamental and ubiquitous process in cognition. Although defining and operationalizing implicit learning remains a central theoretical challenge, scientists' understanding of implicit learning has progressed significantly. Beyond establishing the existence of "learning without awareness," current research seeks to identify the cognitive processes that support implicit learning and addresses the relationship between learning and awareness of what was learned. The emerging view of implicit learning emphasizes the role of associative learning mechanisms that exploit statistical dependencies in the environment in order to generate highly specific knowledge representations.

Keywords

cognitive psychology; learning; consciousness; awareness

Have you ever wondered why it is that you can speak your native language so well without making any grammatical errors although you do not know many of the grammatical rules you follow? Have you ever wondered how it is that you can walk properly although you cannot describe the rules of mechanics your body must certainly follow? These two examples point to an important human property, namely, the ability to adapt to environmental constraints—to learn—in the absence of any knowledge about how the adaptation is achieved. *Implicit learning*—laxly defined as learning without awareness—is seemingly ubiquitous in everyday life.

In this article, we try to provide an overview of the difficulties research on implicit learning has been facing and of the advances that have been made in scientists' understanding of the concept. More specifically, we discuss three separate issues. First, we address what is meant by implicit learning and how the concept has been empirically approached in the recent past. Second, we summarize what is currently known with some certainty about the cognitive processes underlying implicit learning and the mental representations that are acquired through it. Third, we discuss some of the most important current topics of investigation.

DEFINITION AND OPERATIONALIZATION

The one basic theoretical issue that reigns supreme among the difficulties facing researchers concerns the definition and operationalization of implicit learning. Although it seems clear that implicit learning needs to be viewed in opposition to learning that is not implicit (often called explicit, hypothesis-driven learning), it has so far proven extremely difficult to provide a satisfactory definition of implicit learning. At least a dozen different definitions have been offered in the field.

One important consequence of the heterogeneity of definitions is that different researchers have operationalized implicit learning in different ways. For example, Arthur Reber, whose early work in the 1960s rekindled interest in implicit learning, has done most of his empirical work with artificial-grammar-learning tasks. In these tasks, participants are asked to memorize a set of letter strings, such as "XXRTRXV" and "QQWMWQP," that are, unbeknownst to the participants, generated by some rules. After the memorization phase, participants are told that the strings they memorized followed certain rules, and are asked to classify new strings as grammatical (i.e., following the rules) or not. Typically, participants can perform this classification task with accuracy better than would be expected by chance, despite remaining unable to verbally describe the rules.

Thus, in a grammar-learning task, participants learn about permissible and nonpermissible combinations of letters that are presented simultaneously. By comparison, in another task often used to investigate implicit learning, the serial reaction time task (SRTT), participants learn about permissible and nonpermissible combinations of spatial locations that occur over time. In the SRTT, participants are asked to select and depress a key that matches each of the locations at which a stimulus appears on a screen. The sequence of locations at which the stimulus appears is fixed. In general, participants seem to be able to learn the sequence of spatial locations even when they are not able to verbally describe it.

Divergent definitions of implicit learning entail divergent operationalizations of the concept, but even researchers who agree in their definitions might use experimental tasks that differ in what exactly participants might learn. Therefore, it remains an open empirical issue to what extent results from a given task that has been used to probe implicit learning can be generalized to other tasks. This point leads to our first conclusion:

- *Conclusion 1.* Implicit learning of Task A is not necessarily comparable to implicit learning of Task B. Neither the properties of the learning mechanisms involved nor the acquired mental representations need be the same. It is even conceivable that implicit learning of Task A might be possible, but implicit learning of Task B might not.

THE KEY ISSUE

Regardless of how implicit learning is defined and operationalized, the key empirical issue that research needs to address is whether or not learning that is "implicit" is possible, and if it is, whether implicit learning is different from learning that is "not implicit." Many researchers have for practical reasons adopted as their definition of implicit learning "the capacity to learn without awareness of the products of learning." Thus, learning is assumed to be "implicit" when participants are unaware of what they learned. Alternatively, learning is assumed not to be implicit when participants are aware of what they learned. In other words, implicit learning is defined in terms of its product rather than the properties of the learning process.

Various measures have been proposed to assess awareness of the products of learning. The most notable measures are verbal reports and forced-choice tests (such as recognition tests).

Participants in implicit-learning experiments have consistently been shown to be able to acquire knowledge that they cannot verbally describe. This appears to be true for a wide variety of tasks, including the grammar-learning and sequence-learning tasks we described earlier. Thus, if verbal report is used to assess awareness of acquired knowledge, many experimental findings appear to support the conclusion that implicit learning is possible.

However, many authors have argued that verbal reports may have poor validity. First, it has been argued that the verbal-report data do not pass the information criterion; that is, the information assessed by verbal recall tests is not always the same information that has led to the demonstrated learning. Second, verbal recall tests might not pass the sensitivity criterion; that is, they may not provide a level of sensitivity that is comparable to that of tests demonstrating learning in the first place. Many researchers have therefore suggested that awareness should be assessed by forced-choice tests, such as recognition tests, rather than verbal recall.

In the grammar-learning paradigm, participants are sometimes asked to complete recognition tests after they have categorized letter strings as grammatical or nongrammatical. For example, in some studies participants were asked to indicate for each letter string which particular letters they thought made the string grammatical or not. It was found that participants' markings correlated with their classification performance, suggesting at least partial awareness of the knowledge learned.

Similar findings have been obtained in studies that have used other implicit-learning paradigms. For example, after participants had completed the SRTT, they were presented sequence patterns of varying lengths in numerical form. Each sequence (e.g., 123432) denoted a series of locations on the computer screen. Participants were asked to mark patterns that they had encountered during the experiment as true and patterns that they had not seen as false. It was found that participants' recognition scores correlated with their learning scores for the SRTT. In general, many different studies using different experimental paradigms have used forced-choice tests to assess awareness of the acquired knowledge, and these studies appear not to support the existence of implicit learning.

However, it has been argued that this particular interpretation rests on the assumption that the forced-choice tests are pure assessments of awareness (i.e., are process pure). This is almost certainly not the case. Indeed, participants might choose a correct answer on a forced-choice test not because they are aware of the fact that it is the correct answer but because they rely on some intuition that they are not able to express. The growing understanding that tests are rarely process pure has fostered the use of new methodologies that are not based on this assumption. For example, Jacoby's process dissociation procedure offers a measure of awareness that is derived from experimental conditions that are believed to trigger both implicit and nonimplicit processes simultaneously. This consideration of how awareness should be assessed leads to our second conclusion:

- *Conclusion 2.* Many researchers have tried to avoid the difficult issue of how to define implicit learning and have, often without stating so explicitly, adopted the stance that implicit learning is the capacity to learn without awareness of the products of learning. However, it has become clear that the amount of support for implicit learning varies considerably with the specific measure that is selected to assess awareness of what was learned. Thus, by avoiding the issue of how to define implicit learning, researchers have introduced the problem of how to define awareness. In the end, the definitional question has not been resolved, but has merely been transferred from one concept to another.

MECHANISMS OF LEARNING AND AWARENESS

Even when implicit learning (in the sense of learning that yields knowledge the learner is not aware of) is demonstrated conclusively, one learns little about the mechanisms underlying implicit learning. It is helpful to consider the different ways in which, in principle, learning and awareness of the products of learning might be related. Figure 1 depicts five of the many distinct possibilities that have been proposed.

First, it is, of course, conceivable that learning and awareness of what has been learned are perfectly correlated. According to this proposal, implicit learning does not exist. As is shown in Figure 1a, learning might be achieved by a single mechanism that generates memory representations a learner is always aware of.

According to the four remaining possibilities, learning and awareness need not be—but might be—perfectly correlated. According to the second possibil-

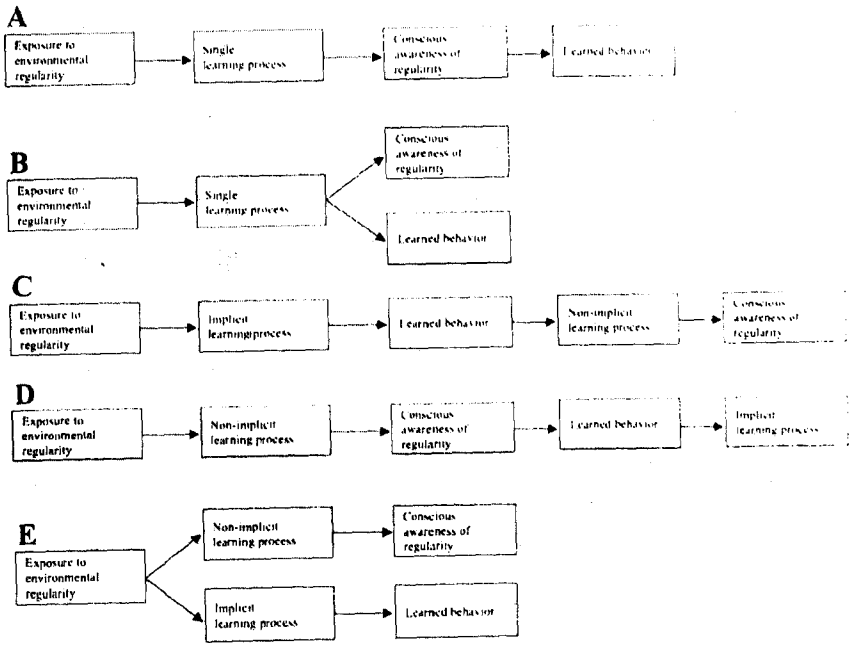

Fig. 1. Possible relations between learning and awareness of what was learned.

ity, depicted in Figure 1b, a single learning mechanism is assumed to create memory representations that control behavior. Some of the learned memory representations might be open to awareness; some might not be.

The last three possibilities (Figs. 1c–1e) allow for truly implicit learning. According to the third possibility, an implicit-learning mechanism might generate memory representations that control behavior. The perception of one's own behavior, in turn, might lead to nonimplicit (i.e., hypothesis-testing) learning that might generate awareness of what was learned (Fig. 1c). Under this view, the effects of implicit learning are an important trigger for nonimplicit learning. For example, a tennis player might perceive an increased accuracy of her serve. She might then conclude that the reason for this improvement is to be found in a slightly higher toss of the ball.

The fourth possibility is that nonimplicit learning might lead to awareness of what was learned, and might control behavior. The expression of behavior, in turn, might provide the input for the operation of an implicit-learning mechanism (Fig. 1d). For example, most tennis players know that solid ground strokes require a player to move toward the approaching ball instead of away from it. The conscious effort to engage in a forward movement may lead to learning within the motor systems that lies largely outside of conscious awareness.

The fifth possibility, shown in Figure 1e, is that there exist two distinct learning mechanisms, with one of the mechanisms generating memory representations that a learner is aware of, and the other mechanism generating representations that a learner is not aware of but that nevertheless control behavior.

Most of the research that has been concerned with the difference between implicit and nonimplicit learning has not addressed which possibility in Figure 1 describes the nature of implicit learning, but rather has tried to demonstrate that learning is possible in the absence of learners' awareness of the acquired knowledge. However, several attempts have been made to distinguish the two-systems hypothesis (i.e., that there are separate systems for implicit and nonimplicit learning), represented by the possibilities depicted in Figures 1c through 1e, from the single-system hypothesis, represented by the possibilities depicted in Figures 1a and 1b. The relative adequacy of these two hypotheses can be assessed by exploring the potentially differing influence of variables such as intention to learn, attention, age of participants, individual differences in intelligence, stimulus complexity, and task demands on learning with awareness and on learning without awareness.

For example, researchers have explored the possibility that implicit and nonimplicit learning might be differentially affected by age. With the SRTT, it has been found that implicit learning is less affected by age than is learning that is based on hypothesis testing. Indeed, implicit learning in the SRTT does not appear to begin to decline until relatively old age, and even then, the elderly display performance levels that are much closer to those of younger adults for implicit-learning tasks than for nonimplicit-learning tasks involving, for example, problem solving, reasoning, and long-term memory. On the whole, this research therefore lends some credibility to the multiple-systems view.

Also, both neuropsychological studies and neuroimaging studies have addressed the adequacy of the multiple-systems and single-system hypotheses. For example, early studies suggested that even densely amnesic patients can show near-normal implicit learning in both the grammar-learning and the sequence-learning paradigms, although they are specifically impaired on recognition and prediction tasks. More recent critical reexaminations have, however, demonstrated that amnesic patients do seem to show a deficit in implicit learning compared with normal control participants; it is therefore unclear whether or not the findings, on the whole, support the multiple-systems view.

Brain-imaging techniques have increasingly been used to study implicit learning in the SRTT. Although some results suggest that partially distinctive brain areas are involved in implicit and nonimplicit forms of learning, it is, at present, not clear whether these findings should be interpreted as evidence supporting the multiple-systems view or as evidence supporting a "single-system plus awareness" view (depicted in Fig. 1b).

Consideration of the cognitive mechanisms that might be involved in implicit learning leads to our third conclusion:

- *Conclusion 3.* Defining implicit learning with respect to awareness of the products of learning has drawn attention away from the mechanisms that are responsible for the generation of different forms of knowledge. Despite a continuously increasing amount of empirical data, the debate between multiple-systems proponents and single-system proponents has not been settled yet. Furthermore, the question of how exactly awareness and learning might be interrelated has only recently begun to be addressed empirically.

IMPORTANT ADVANCES MADE

If one agrees with the use of verbal-report measures to assess awareness, then recent research on implicit learning has modified earlier theoretical beliefs in important ways. Earlier work had characterized implicit learning as a mechanism by which abstract knowledge of regularities that are present in the environment is acquired automatically and unintentionally by mere exposure to relevant instances. The proposal of a smart unconscious was based, to a large extent, on empirical findings with the grammar-learning task that appeared to show that participants possessed abstract knowledge about the rules of the grammar that went beyond the surface characteristics of the information encountered. This claim seemed further supported by findings indicating that implicitly acquired knowledge may transfer across modalities; for example, learning from a task involving written letters (visual stimuli) can transfer to performance in a task involving letter sounds (auditory stimuli).

This view has been challenged, however, by many recent findings. For example, it has been repeatedly shown that implicitly acquired knowledge might consist of little more than short fragments or chunks of the materials encountered in an implicit-learning situation. In the wake of these findings, neural-network models and fragment-based models that are capable of simulating a great deal of the available experimental findings have been developed. These models utilize representations of elementary stimuli in the learning situation (e.g., representations of letters in a grammar-learning task) and associations between the repre-

sen ns. Learning consists of a continuous, incremental change in the associative pattern that is sensitive to the statistical features of the set of items or events encountered. Thus, a representation of the implicit-learning situation that is shaped by statistical constraints gradually evolves. Although the characterization of implicitly acquired knowledge is still a matter of debate, the current trend is to assume that abstract knowledge might not be implicitly generated.

Many recent studies have explored whether implicit learning, unlike non-implicit learning (i.e., explicit hypothesis testing), proceeds automatically, without the use of attentional resources. By far, most of these studies have used the SRTT, often manipulating the amount of attentional resources available to participants by asking them to perform the SRTT either by itself or together with a secondary task (typically a tone-counting task).

In general, it has been found that implicit learning takes place both in the presence and in the absence of a secondary task. What remains unclear, at present, is the extent to which implicit learning is affected by the attention manipulation. Some researchers argue that the secondary task interferes with task performance rather than with implicit learning proper (i.e., that the secondary task impedes the expression of what has been learned). Under this view, implicit learning does not depend on the availability of attentional resources. Others take the stance that the learning process itself is adversely affected by the presence of a secondary task and thus requires attentional resources.

On the whole, the experiments that have been conducted all suffer from the problem that attention itself is an ill-defined concept that might refer to both mental capacity and selection. In the latter sense, "attention" points to the problem of allocating cognitive resources to a specific item or event. When "attention" is used synonymously with "mental capacity," it instead refers to a limitation of cognitive resources that becomes apparent when resources have to be shared by concurrent cognitive processes. When these two factors are separately and experimentally manipulated, it appears that implicit learning occurs only when stimuli are relevant to the task and are attended to, but that implicit learning may require no or very little mental capacity.

Recent advances in researchers' understanding of implicit learning lead to our fourth conclusion:

- *Conclusion 4.* The early proposal of a smart unconscious capable of acquiring abstract knowledge in an effortless, automatic manner has been replaced recently by the assumption of one or more implicit learning mechanisms that operate mostly associatively. These mechanisms pick up statistical dependencies encountered in the environment and generate highly specific knowledge representations. It is likely that the mechanisms operate only on information that is attended to and that is relevant to the response to be made.

CONCLUSIONS

Researchers' understanding of implicit learning has come a long way. Today, many believe that implicit learning exists, and furthermore that it is based on relatively simple learning mechanisms. These mechanisms associate environmental stimuli that are attended to and that are relevant for behavior. Despite the recent advances, however, the field still suffers from a number of unresolved empirical and theoretical issues. First, there exist conflicting results regarding the role of attention in implicit learning. Second, the exact relation between learning and awareness (see Fig. 1) is very much unknown. Third, the key theoretical issue of how to define implicit learning has still not been resolved.

We strongly believe that progress on the former two (empirical) issues will be made soon and will be based on improved methodology and the joint use of computational modeling and functional brain-imaging techniques. Progress on the key theoretical issue can come, however, only from theoretical advances in understanding of the concepts of "consciousness," "awareness," and "intention." To achieve this progress might require the joint efforts of philosophers, neuroscientists, and cognitive psychologists.

Recommended Reading

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Note

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Critical Thinking Questions

1. Provide a simple definition of implicit learning that captures what researchers have in mind.
2. What are some examples of skills that we have all learned to perform without knowing how we do it?
3. How do researchers determine if a subject's learning is implicit as opposed to explicit?