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Learning and Development

The Implicit Knowledge Assumption Reconsidered

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INTRODUCTION

Learning and Development

Many studies have addressed the question of whether the characteristics of learning differ between adults and children, or between children of different ages. The focus of these studies, from the developmentalist's standpoint, is one of investigating the evolution of a target behavior. Accordingly, learning as a target behavior has the same status as sensory-motor or perceptual phenomena in other domains of developmental psychology. From the learning researcher's standpoint, in contrast, the focus of age-comparative studies is one of demonstrating dissociations between different learning processes. Children, as the selected population, have the same status as elderly people or neurological patients in other domains of the psychology of learning. In virtually no case has the fact that learning and

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development share an interest in the same fundamental issue, namely the acquisition of new skills or new knowledge by a person as a consequence of his or her interaction with a structured environment, led to the search for a common theoretical framework. Exceptions were the well-known early Watson and Skinner attempts to encompass child development within the models of conditioning, but these attempts have failed to generate a long-standing research program. By and large, learning and development have evolved as two independent fields of inquiry.

This independence has multiple determinants. For years, the main focus of interest for learning-oriented researchers has been elementary conditioning phenomena. At first glance, the situation of a subject faced with the repeated presentation of paired events, such as a tone and an electric shock, bears little resemblance to the real-world in which a child grows up. Likewise, theories elaborated in this context seem ill-suited for developmental issues. Of course, some authors have been concerned with more complex forms of learning, for instance, in research on concept formation. However, the nature of the problems, the mode of presentation of the data, the instructional demands for analytic and explicit modes of resolution, all appear to differ from the common situation of a child learning in his or her natural environment.

We believe that the recent upsurge of research on implicit learning provides a unique opportunity for a theoretical integration of the issues raised in the learning and developmental areas. The term *implicit learning* designates an adaptive mode in which subjects' behavior is sensitive to the structural features of an experienced situation, without the adaptation being due to an intentional exploitation of subjects' explicit knowledge about these features. Although there is little consensus within the literature, these two components, (a) the behavioral sensitivity to the structure of a situation, and (b) the lack of intentional, strategic causes for this sensitivity, have been included in virtually all definitions of implicit learning (e.g., Cleeremans, 1993; Reber, 1993). Many contributors to the area have added additional criteria. For instance, several researchers emphasize the point that explicit knowledge about the training situation is lacking or at least limited. Including this property in the implicit learning concept is obviously possible, insofar as terminological issues are arbitrary, but, as a matter of fact, doing so may well make the very existence of the phenomenon controversial (e.g., Shanks & St. John, 1994). The exclusive reliance on a lack of intentional exploitation of explicit knowledge, on the other hand, makes the existence of the phenomenon "real" at the phenomenological, introspective level,

and it is confirmed by a large number of experimental investigations. This choice of definition has the additional advantage of unifying the meanings of implicit across the germane areas of implicit learning and implicit memory.

Examining the characteristics of the experimental situations usually involved in this field of research helps to understand why implicit learning is, a priori, relevant for development. First, implicit learning is generally observed while subjects are not asked to search for the rules structuring the situation they are tackling. Instead, subjects are generally instructed to engage in rote memory or any other activity ensuring attentional processing of the training display but diverting them from taking an analytical approach. Second, only well-structured patterns are displayed. For instance, in the category learning subarea, only positive instances of the to-be-learned category are shown to subjects. This condition contrasts with traditional concept-formation settings, in which subjects are shown both exemplars and nonexemplars of the concept (along with appropriate information). Note that this characteristic is a prerequisite for incidental conditions of learning because showing negative exemplars may well cause a shift within the learner toward adopting a problem-solving attitudinal set. The third characteristic of implicit learning situations is their relative complexity. On the whole, the implicit learning conditions are closer to most real-life situations encountered by children than were the conditions used in earlier, more traditional settings of learning.

However, we do not claim that the mapping between learning in an implicit learning situation and during development is perfect. The most salient differences between laboratory situations of implicit learning and the situations encountered in natural learning settings throughout childhood pertain to their duration and level of complexity. It may indeed appear absurd to draw a parallel between what happens during the few minutes of a typical implicit learning session and the full course of human development from infancy to adulthood. Likewise, the complexity of the typical implicit learning situation, although higher than in traditional laboratory studies, shows little resemblance to the complexity of natural languages or physical laws, for instance. This problem must not be ignored. In addition, parents, and mostly teachers, tend to design learning situations for children that do not necessarily display the characteristics of implicit learning situations. Our claim is, therefore, not that a laboratory learning session mimics the whole of development; our working hypothesis is only that an implicit learning session taps, at least partially, the same general acquisition processes that shape developmental sequelae.

This working hypothesis is tacitly adopted in most introductory texts on implicit learning. Many contributors to the implicit learning area endorse the view that implicit learning is responsible for at least some aspects of first-language (e.g., Chandler, 1993) and second-language learning (e.g., Carr & Curran, 1994), category elaboration, reading and writing acquisition, adaptation to physical constraints of the world (e.g., Krist, Fieberg, & Wilkening, 1993), and acquisition of social skills (e.g., Reber, 1993). Noteworthy, most of this learning takes place during childhood and constitutes the essentials of what a newborn must acquire to become an adult. However, the literature on the relation between implicit learning and development is sparse, to say the least. The few articles we are aware of (Maybery, Taylor, & O'Brien-Malone, 1995; Roter, 1995) have investigated whether the characteristics of implicit learning differ between children and adults, in line with the traditional approach described above. The integrative view we propose in this chapter goes further because theories of learning and development are considered jointly.

Overview of the Chapter

Most of the many theoretical approaches to implicit learning share a basic postulate, namely, that behavioral sensitivity to the structural aspects of the environment, unmediated by an intentional exploitation of explicit knowledge, testifies to the formation and the use of an implicit knowledge base. However, the validity of this notion has been questioned in view of empirical data and theoretical arguments. A landmark feature of the perspective adopted here, which will be exposed below (see also Perruchet & Gallego, 1997; Perruchet, Vinter, & Gallego, 1997; Vinter & Perruchet, 1994), is that it leaves no room for the notion of implicit knowledge.

However, most of the dominant developmental theories adhere to the notion of implicit knowledge or implicit representation. At first glance, this situation deeply undermines the validity of our account, which has been derived from the most common laboratory situations of implicit learning, the sequence-learning and artificial grammar-learning tasks. Indeed, the apparent discrepancy between our account and dominant developmental theories suggests that our view may be unable to account for learning in complex natural settings. This inability, if confirmed, would seriously undermine our approach, even within its limited original context. However, in the implicit learning literature, the rejection of the notion of implicit knowledge stems from the reappraisal of earlier data and arguments that

had been initially put forth in support of the notion. It is therefore conceivable that the same kind of reappraisal may be applied to the data and arguments currently put forth in the developmental literature to support the notion of implicit knowledge. In this chapter, we explore this possibility. In the next two sections, we present our theoretical framework of implicit learning. We then turn to a discussion of some dominant developmental theories that start from postulates opposite to ours. We will examine how some of the data on which these theories are based can be reanalyzed along the same principles that have led to a reinterpretation of the data in the implicit learning area. To anticipate, we will conclude that our account of implicit learning challenges the current focus on implicit knowledge in developmental theories more than the reverse.

As a last introductory remark, some words are necessary about what is meant by implicit knowledge in the implicit learning field, given that the rebuttal of this notion is at the core of the present chapter. This is difficult because the expression is generally used without further specifications. According to Berry and Dienes's (1993) synthesis, which appears to be one of the most systematic reflections on the topic, the main characteristic of implicit knowledge is its relative unavailability to consciousness. The authors write, "The inaccessibility of the knowledge seems to have been the starting point of most researchers' understanding of the claim for implicit knowledge" (p. 145). Berry and Dienes propose additional, secondary characteristics, such as a stronger robustness of implicit than explicit knowledge. The important point for our concern is that Berry and Dienes do not mention any differences pertaining to the contents of implicit and explicit knowledge. Although there are deep controversies about the actual content of implicit knowledge, with some authors positing that subjects abstract the rules underlying learning situations and store these rules in an abstract representational format (e.g., Reber, 1993), and other authors arguing that subjects memorize and store specific episodes of the learning situations (e.g., Neal & Hesketh, 1997), these properties are not construed as specific to a particular form of knowledge, implicit or explicit. Thus, a good approximation to the notion of implicit knowledge appears to be that it designates the same kind of knowledge that can be accessed introspectively (with possible variations on the dimension of abstractness), but that it is deprived, to some extent, of introspective availability. It is worth adding that the exact meaning of this last characteristic is itself controversial, with some authors arguing that unconsciousness is demonstrated only by chance level results in forced-choice tests (e.g., Shanks & St. John, 1994), and other authors contending that knowledge may be termed implicit when it is difficult to access with free-report procedures (e.g., Dienes & Berry, 1997). This issue will not be further elaborated in the present chapter. To provide more generality to our proposal, the term implicit will be used here with reference to its looser meaning.

A CASE STUDY: THE LEWICKI, HILL, AND BIZOT EXPERIMENT

Before we present our own theoretical account of implicit learning, let us begin with an example to illustrate how experimental data that, at first glance, support the notion of implicit knowledge, can be understood and interpreted in different terms. The paradigm under examination was initially designed by Lewicki, Hill, and Bizot (1988). In this paradigm, subjects are submitted to a four-choice reaction time (RT) task, with the targets appearing in one of four quadrants on a computer screen. Subjects are asked to track the targets on the numeric keypad of the computer as fast as possible. To subjects, the sequence appears as a long and continuous series of randomly located targets. However, in reality, the sequence is structured according to subtle, nonsalient rules. Specifically, the sequence is partitioned into a succession of logical blocks of five trials. In each block, the first two locations of the target are randomly selected, and the last three locations are determined by rules of the form: If the target describes a movement m while it moves from location $n - 2$ to location $n - 1$, then it describes a movement m' from location $n - 1$ to location n. As a function of whether n is the third, fourth, or fifth trial of the logical block, if m is horizontal (resp. vertical and diagonal), then m' is vertical or diagonal. Note that discovering these second-order dependency rules imperatively requires the segmentation of the entire sequence into a succession of five-trial subsequences. That is, any trial within the long sequence must be identified as the first, second, . . . , fifth trial within the logical five-trial block to which it belongs.

The results of Lewicki et al. (1988) were straightforward. Subjects were unable to verbalize the nature of the manipulation, and especially they had no explicit knowledge about the partitioning into logical blocks of five trials, which is a prerequisite for catching the rules. This finding is unsurprising, given the complexity of the situation (we suggest the skeptical reader conceive of a general purpose algorithm that could detect the presence of logical blocks in Lewicki et al.'s sequences). However, performance on the last trials of each block, the locations of which were predictable on the basis of the rules, improved at a faster rate and was better overall than performance on the first random trials.

Lewicki et al. (1988) accounted for these results by arguing that the structuring rules were discovered by a powerful, all-purpose unconscious algorithm abstractor. The rules thus became the constituents of subjects' implicit knowledge. Perruchet, Gallego, and Savy (1990), however, formed the basis for a radically different interpretation by demonstrating that subjects may have learned the task without ever performing the segmentation of the sequence into logical blocks. Rather, subjects may have been sensitive to the relative frequency of small units, comprising two or three successive locations. Some of the possible sequences of two or three locations were more frequent than others because the rules determining the last three trials within each five-trial block prohibited some transitions to occur. In particular, examination of the rules showed that they never generated back and forth movements (i.e., m' is never the inverse movement of m). As a consequence, back and forth transitions were less frequent in the entire sequence than the other possible transitions. The crucial point is that these less frequent events, which presumably elicit longer RTs, were exclusively located in the random trials. This stems not from an unfortunate bias in randomization but from a logical principle: The composition rules determined both the relative frequency of some events in the whole sequence and the selective occurrence of these events in specific trials. The validity of the Perruchet et al. interpretation was tested by deriving predictions for performance on specific features of the sequence, both from an abstractionist view and from our alternative view. Empirical data, confirmed by a connectionist modeling approach (Cleeremans, 1993), supported our reanalysis.

According to Lewicki et al. (1988), subjects acquire an implicit representation of the segmentation of the sequence into logical blocks. It could be argued that our reappraisal of the original data leads to a content modification of the implicit knowledge base, from abstract rules to representations of event frequencies. But let us go even further in our reconceptualization. There is in fact no need to postulate the formation of an implicit knowledge base that contains frequency representations. The subsequences of events considered by Perruchet et al. (1990), such as diagonal and back and forth movements of the targets, are presumably the events on which the subjects focus attention. These events are fully conscious to subjects, in the sense that they shape subjects' phenomenal experience with the task. What changes with training is the phenomenal experience itself. Some salient sequences of events are experienced as more familiar than other sequences. This change in the conscious, online perception of the task exerts direct influences on RTs. It may also exert influences on other tasks, notably so-called explicit knowledge tests. For instance, in the last phase of the Perruchet et al. (1990) experiment, participants were asked to predict the location of the next occurrence of the target. Their predictions turned out to be sensitive to the relative frequency of the salient events displayed during training.

It is important to emphasize the radical difference between the Lewicki et al. (1988) interpretation, which is taken here to instantiate the conventional account of implicit learning, and the interpretation introduced by the Perruchet et al. (1990) reappraisal of the data. In the former view, exposure to the material leads to the formation of implicit knowledge about its structuring features. Changes in performance are due to the unconscious exploitation of this implicit knowledge base, with all of the presumed processing being unavailable to subjects' consciousness. In the latter interpretation, there is no place for the notions of implicit knowledge or implicit representation. Exposure to the material shapes the way the material is consciously perceived and processed. The modification of the phenomenal experience triggers both the improvement in motor performance and the results in so-called explicit tests. Note that in this formulation, the debate on how to best assess consciousness becomes meaningless. The question of the extent to which knowledge acquired in an implicit learning episode is explicit no longer makes sense because conscious experience is construed as the end product of implicit learning.

A SUBJECTIVE UNIT-FORMATION ACCOUNT OF IMPLICIT LEARNING

General Outline of the View

Our general view of implicit learning underlying the reinterpretation of the Lewicki et al. (1988) data will be outlined next (for a more extensive presentation, see Perruchet & Gallego, 1997). This view may be condensed into a few key points, listed below.

1. With their first exposure to the material displayed in any implicit learning situation, subjects begin to parse the material into small and disjunctive (i.e., nonoverlapping) units. These units are composed of the primitive features that are processed conjointly in the attentional focus, and as such, determine the conscious, phenomenal apprehension that subjects have of the material. The size of these units is determined by capacity limitations inherent to attentional processing, and their composition is induced by both subjects' background knowledge and surface-salient features of the material, such as those evidenced by Gestalt theorists. For instance, in the situation described above, the displacement of the target may be perceived as a succession of horizontal, vertical, and diagonal movements, back and forth displacements, or longer units, such as complete clockwise turnovers of the target around its different possible locations. These units will be referred to as sensory-based units hereafter.

2. While training progresses, the sensory-based units are selected and modified such that they provide a conscious coding of the material that is increasingly relevant to the structure of the task. This crucial phenomenon is a mandatory, automatic consequence of the attentional processing of the input data. The reason is that attention triggers the action of unconscious associative mechanisms, which have remarkable power to provide an optimal parsing of the material, as will be detailed later.

3. Concurrently, the sensory-based units become increasingly independent of the sensory input and form conscious internal representations. Sensory-based and internal units are not qualitatively different, and hence they may be seen as the end points of a continuous dimension. Hereafter, the term *subjective units* will be used to designate both sensory-based units and internal representations, the difference being their degree of dependence on sensory input. Subjective units are the constituents of phenomenal consciousness.

4. Subjective units form the new primitives of subsequent attention processing and can hence enter into the building of higher-level units. The possibility of hierarchical processing provides great explanatory power for learning in very complex settings.

5. The formation of subjective units that become increasingly congruent with the structure of the material is directly responsible for the improvement in performance observed in so-called implicit learning tasks. Thus, performance improvement is indicative of a change in the conscious perception and representation of the environment, due to the action of unconscious associative processes.

6. The mechanisms outlined above do not account for every form of behavioral adaptation. We are dealing here with implicit learning processes solely. Therefore, it is worth stressing that some forms of adaptive behavior are completely beyond the scope of this chapter because they necessarily require intentionally guided processes such as logical inference, hypothesis testing, or any form of abstract reasoning. For instance, genuine knowledge of the abstract rules governing Lewicki et al.'s (1988) situation cannot be achieved with the involvement of implicit learning processes alone, whatever the amount of training. This does not mean that human subjects are unable to find these rules. It means that these rules can only be discovered by means of an effortful inferential procedure. Note that implicit learning processes, by providing a coding of the material that tends to make its deep structure directly available to consciousness, provide a suitable preparation for a later analytical, problem-solving approach (see Vinter & Perruchet, in press, for a comment on this point).

To summarize, implicit learning forms the basis of conscious experience, that is, it shapes both subjects' perception and internal representation of the world. Because subjects have conscious perception and representations before starting any implicit learning episode, *implicit learning may be thought of as allowing to pass from earlier conscious perceptions and representations to later, generally better structured, conscious perceptions and representations through the action of intrinsically unconscious mechanisms.* Because our contention stands in straight opposition to the dominant stance of the literature (but see Dulany, 1997, for an exception), a bit of introspection may be needed to intuitively capture the likelihood that our proposal is correct. Let us consider any natural situation of implicit learning, whether this situation concerns the acquisition of language, reading and writing abilities, or sensitivity to musical structure. It is hardly defensible that our subjective experience of the part of the environment with which we interact, as well as our representation of it, remains unmodified while training progresses. Our claim is simply that the changes in the way we consciously perceive, represent, and interact with this environment are at the core of implicit learning.

In this account, the concept of implicit knowledge has no place. In any implicit learning setting, performance improves because subjects carry out a conscious coding of the material that is increasingly congruent with the structure of the material. What provides the illusion that there is some hidden knowledge is the increasing efficiency of the conscious coding.

This change is attributed to the action of intrinsically unconscious associative processes. Next, we discuss in more detail the way in which unconscious associative processes can provide an optimal parsing of the training material.

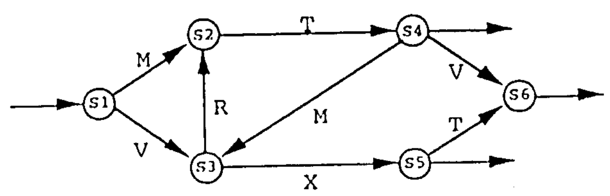
The Formation of Optimal Subjective Units

The formation of subjective units is linked to the question of how information is parsed during processing. Such a question is particularly relevant for an understanding of early cognitive competence in childhood and has indeed received much attention from researchers who try to understand the abilities shown by neonates. Because we will argue that these early abilities rely on the same parsing mechanisms that are involved in implicit learning, a somewhat detailed discussion of this issue is worthwhile.

In the present section, we illustrate and analyze the parsing mechanisms using the artificial grammar-learning situation, which has been investigated far more extensively than the Lewicki et al. (1988) situation described above (note that Stadler, 1995, has proposed a theoretical account of implicit learning in serial reaction time [SRT] tasks that bears some resemblance to the following analysis). As is now well-known (see Reber, 1993, for a general discussion of the artificial grammar-learning paradigm), subjects in an artificial grammar-learning situation are familiarized, during the study phase, with a set of grammatical strings. There is considerable evidence that subjects partition this material during its coding. For example, when subjects are asked to write down the study items of an artificial grammar experiment, they frequently produce strings consisting of groups of letters (Servan-Schreiber & Anderson, 1990). Likewise, when subjects are asked to give verbal instructions to yoked partners during the study phase about what they should be looking for, they often refer to subunits, such as bigrams or trigrams (Mathews et al., 1989).

Our account of this ubiquitous form of coding is grounded on a general model of associative learning in which attention devoted to the stimulus is viewed as the major explanatory principle for the formation of subjective units. More precisely, the claim is that a new unit is formed as an automatic and mandatory consequence of the concurrent attentional processing of a few events (Frensch & Miner, 1994). Such a position has been expressed primarily in the conditioning field (e.g., Mackintosh, 1975), but also in other contexts. For instance, Ceraso (1985) has emphasized the role of initial perceptual processes in the formation of psychological units, and

(a)



(b)

M T/M/R T/V	M T/M/R T/V
M T/V	M/T V
V/R T/M/X T	V R/T M/X/T
V/X T	V X/T

Figure 15.1. Panel (b) shows two modes of segmentation of four-letter strings generated by the finite-state grammar represented in panel (a). In the leftmost segmentation, only 5 different units are needed because they match with the main paths of the grammar. In the rightmost segmentation, which is random, 10 different units are necessary.

Logan and Etherton (1994) have highlighted the role of attention in constructing instances. In this kind of framework, subjective units stem from the concurrent processing of the primitives of the situation that may be simultaneously apprehended during the initial coding. If one considers that letters are the primitive features in artificial grammar-learning tasks for literate subjects, then the size of the units can be directly traced to the limited capacity of perceptual attentional processes.

Attentional limitations explain why continuous information is partitioned, but the fact we have to account for is that the resulting parts, which are initially induced by surface-salient features or determined by subject's background knowledge, increasingly match the structurally relevant units while training progresses. Let us consider the finite-state grammar shown in Figure 15.1a and two possible modes of segmentation of a few strings generated by this grammar in Figure 15.1b. In the first mode, the components match the main paths of the grammar, whereas they are at random in the second mode. Although the total number of units does not differ for

the two modes of parsing (and hence the mean lengths of the units are identical), it may be seen that the strings can be described as composed of 5 or 10 different units, respectively. Clearly, describing the material with a smaller number of different units is much more economical. It is easier to learn few units, some of which are repeated, than a larger number of different units that are each presented once.

There exists empirical evidence suggesting that subjects effectively realize an increasingly efficient segmentation. In an unpublished experiment from our laboratory, subjects were asked to read each string generated by a finite state grammar and, immediately after reading, to mark with a slash bar the natural places of segmentation. Subjects repeated this task after a phase of familiarization with the material, which consisted either of learning items by rote, performing a short-term matching task, or searching for rules. Subjects formed the same number of total units before and after the training phase, thus indicating that they did not tend to form increasingly larger units. However, the number of different units reliably decreased, whatever the task during training. Our conclusion is that exposure to structured material modifies the natural coding of the material toward an increasingly more efficient segmentation (see also Servan-Schreiber & Anderson, 1990).

At first glance, selecting units that match the deep structure of a grammar implies sophisticated inductive tools. However, selection can be accounted for in a simplistic way within an associative framework. If one realizes all the possible partitions of a sequence into a succession of units of a given range of size, then the parsing matching the structure of the grammar most efficiently is the parsing in which the number of different units is minimized. A logical correlate of the minimal number criterion is that the final units are the most frequently occurring ones (for any fixed range of size). The detection by subjects of the most frequent units needs no special device but derives from the application of two fundamental principles.

First, in keeping with the ubiquitous beneficial effect of repetition on associative learning, the most frequent associations are privileged. Second, the formation of stable and optimal units may be strengthened by another process, referred to as overshadowing in the conditioning literature. This process prevents the formation of competitive, and infrequent, associative links. One of the major developments in the study of conditioning over the last few decades has been the discovery that associations between contiguous events tend to be selective and exclusive. For instance, if two events

A and B are paired with C, but for some reason (e.g., saliency, position, relative number of pairing), A is a better predictor than B, then the association between B and C is impaired (e.g., Kamin, 1969). Assume that for a string of five events (A, B, C, D, E), the segmentation matching a grammar is AB/CDE. This means that over the entire series of training, items AB and CDE occur more frequently than, say, ABC and DE. Association principles account for the formation of AB and CDE associations, but also for the neglect of less frequent associations because the associations of B with A and of C with D and E prevent the formation of a BC association. This overshadowing effect can be interpreted as an attentional effect, with the most frequent associations capturing all or most of the available attention (e.g., Mackintosh, 1975).

To summarize, the process of forming subjective units appears to be both extraordinarily powerful, insofar as the resulting units are consistent with the structure of the material, and accountable for by elementary and ubiquitous associative processes. Indeed, the only postulate needed is that units emerge as a mandatory consequence of the joint attention to a few primitive stimulus features.

THE CHALLENGE OF DEVELOPMENTAL THEORIES

Preliminary Considerations

Existing theories of development are strikingly heterogeneous, ranging from more nativist approaches to constructivist ones. Although some incursions in other models will be necessary to give more generality to our argument, we have chosen to focus mainly on a theory proposed recently by Karmiloff-Smith (1992), because this theory is grounded in the distinction between an implicit and an explicit knowledge format and thus deals with the relation between the two types of knowledge. To anticipate, we will argue that, as did Reber and Lewicki in their accounts of implicit learning phenomena, Karmiloff-Smith relates early acquired behavioral mastery to the progressive formation of implicit knowledge, which may later become explicit. Of additional interest in the Karmiloff-Smith theory is that not only is it devoted to accounting for specific age-related changes, but that this theory, in contrast to stage models such as Piaget's, also focuses on general acquisition processes in microdomains throughout development, which makes the comparison of learning processes in children and adults easier. Finally, we thought that taking Karmiloff-Smith's model as a privileged target is justified by the widespread interest and approval it has generated within the developmental area, as is evidenced by a recent *Behavioral and Brain Sciences* publication of the model (see Karmiloff-Smith, 1994, and the subsequent peer comments). The large appeal of the model is probably due to the fact that Karmiloff-Smith combined influences from the two main sources of theoretical inspiration in developmental psychology: the constructivist view of Piaget, on the one hand, and the modularist view of Fodor, on the other hand.

The Notion of Implicit Knowledge in Developmental Theories

A brief presentation of Karmiloff-Smith's (1992) model is in order. Adopting a Piagetian constructivist view of development, Karmiloff-Smith argues that a unique (common) schema of development applies recursively to each domain of knowledge. For her, the cognitive architecture is modular, and domains or modules develop independent of each other. Inspired largely by Fodor's nativist view, Karmiloff-Smith also contends that development starts from an already existing basis of knowledge, that is, from innate predispositions or constraints. Consider the case of language acquisition, for example. According to Karmiloff-Smith, at least three kinds of premises are crucial for language acquisition to become a manageable learning problem for the infant: The continuous speech stream must be segmented into meaningful linguistic units, the visual array must be parsed into discrete objects and events, and the mapping between linguistic units and objects/events must be realized. In agreement with a large body of literature, Karmiloff-Smith argues that prestructured knowledge exists from birth with respect to these premises. Innately specified predispositions of the processing system simplify the learning task, guiding and constraining adequately where to focus attention and how to process information. Similar arguments are made for other domains of knowledge, such as the spatial, physical, and numerical domains. If we recall the Lewicki et al. (1988) learning situation, and try to make sense of this situation using Karmiloff-Smith's model, we would suppose that innate predispositions of the processing system would allow subjects to directly segment the incoming information into relevant blocks of five trials, hence making possible the progressive discovery of the second-order dependency rules that regulate the within-block events.

The first developmental phase described by Karmiloff-Smith (1992) is the result of a more or less prolonged period of continuous exposure to, and interaction with, the environment, adequately encoded due to the basic processing predispositions existing at birth. During this period, data-driven processes, such as associative processes, regulation through feedback, trial and error processes, and imitative processes directly shape the child's behavior. A phase of behavioral competence or mastery is thus attained by the child with respect to different skills pertaining to each domain of knowledge. Karmiloff-Smith shows that children aged 3 to 4 years old are perfectly able to manage the use of plurifunctional words in French, like *un* (which means both *a* and *one*), for instance, or to balance parallelepipedic objects on a narrow support even in difficult cases, such as when the center of gravity does not correspond to the geometric center.

Both because the child's cognitive system is adequately tuned to processing the relevant information and because the environment is coherently structured, the knowledge embedded in the efficient procedures making behavioral mastery possible will reflect the basic structural properties of the environment (e.g., objects, events), of the body, and of the actions. Karmiloff-Smith (1992) considers, for instance, that the knowledge appropriate for a metalinguistic understanding of the plurifunctionality of some French words is already embedded in the verbal procedures used by 3- to 4-year-old children. Similarly, she claims that the abstract notion of a gravity center is already embedded in the success of young children in object balancing. However, this knowledge is fundamentally nonaccessible. It is encapsulated in the procedure, in the sense that it is inherent to its functioning. Therefore, this first phase of development is called *implicit level*. The sensorimotor system of knowledge postulated by Mandler (1988, 1992) bears strong resemblance to this implicit level. The sensorimotor system includes procedural knowledge that does not require, according to Mandler, any accessible conscious information (i.e., reaching behavior, locomotion), and perceptual recognition that again does not need conscious access to information, as, for instance, perceptual recognition demonstrated in the habituation-dehabituation paradigm. This system embeds knowledge represented in an implicit format. Again, note how the Karmiloff-Smith model could account for the changes observed in adult behavior in the Lewicki et al. (1988) situation. During their exposure to the learning situation, subjects become increasingly sensitive to its structure, as revealed by RT measures, although they remain unable to report any rules. We could say that subjects are in a phase of behavioral mastery, in which the performance is grounded in representations that are instantiated in an implicit format.

However, despite the fact that a good degree of behavioral mastery is attained, development does not stop here (although it could, as observed for some sensorimotor skills, such as tying shoes, for instance). At a certain moment in time, an endogenous process that Karmiloff-Smith (1992) terms a *representational redescription* (RR), will be elicited. The reasons for the necessity of such a process can be found in the limitations of the previous phase. Efficient procedural skills have been formed during this first phase, which are completely independent, even if they finally embed similar or related knowledge. Furthermore, these procedural skills, and in consequence, the manifestation of the implicit knowledge, are completely under stimulus control, that is, they are completely context-dependent. The knowledge they embed cannot be accessed as a data source by other parts of the cognitive system. A RR process is thus necessary for extracting knowledge from the procedures, making it accessible, and for representing knowledge in a coherent and economical way. The RR process is internally guided and transforms implicit knowledge into explicit knowledge. Knowledge becomes accessible although it is still not conscious for Karmiloff-Smith. Consciously accessible knowledge will emerge in a further step, leading to verbally reportable knowledge in a final step, again through application of the RR process.

For our concerns in this chapter, we may pass over the details of the Karmiloff-Smith (1992) model and concentrate upon the gist of the model: Implicitly stored knowledge underlying early behavioral mastery is subsequently redescribed to become explicit knowledge, possibly verbally stateable at the end of the developmental process. Mandler (1992) seems to agree with this idea in the second version of her model, linking the appearance of image schemas (explicit knowledge) to a redescription of the previous perceptual schemas (implicit knowledge). Consequently, the idea that explicit systems of knowledge emerge in development as a result of a redescription process of implicit systems can be considered to have some generality.

A special case should however be made for one current developmental model (Mounoud, 1993; Mounoud & Vinter, 1981) that offers a quite divergent view on these issues. Basically, Mounoud assumes that the dynamic of development is due to the dialectic relations that exist continuously during development between two systems of knowledge: one that results from previous development, called a *practical system*, consisting of constituted, sedimented knowledge, and a second one, called a *conceptual system*, which consists of new in-built knowledge. The distinction between a practical and a conceptual system of knowledge does not rely on a difference in type of knowledge but designates qualitatively distinct states of development of the same knowledge system. We can illustrate this point with respect to the sensory-motor system of knowledge: It constitutes the conceptual system of knowledge under construction between birth and 2 to 3 years of age, and then the practical system of knowledge above 3 to 4 years of age. The transition between the two phases is gradual and skill-dependent. Reaching for an object, for instance, will achieve a practical form of behavior before locomotion. As Mounoud qualifies practical knowledge as immediate, nonaccessible, and nonconscious, and conceptual knowledge as mediated, accessible, and conscious, it is attractive to consider the possibility that knowledge is implicit in the first system and explicit in the second. Although such a conclusion may indeed be acceptable for the conceptual system (consisting of explicit knowledge), it is far more contentious for the practical system, because practical knowledge is always the result of an earlier conceptually developed system and thus, of an earlier explicit form of knowledge. For researchers in the implicit learning domain, implicit knowledge is clearly to be differentiated from the kind of knowledge alluded to by Mounoud with the term practical, the meaning of which may be closer to *automatic*. In this perspective, we suggest that for Mounoud, knowledge is always explicit but becomes embedded in automatized behavior and, moreover, evolves from a conceptual to a practical form, and not the reverse. Finally, Mounoud's model contrasts also with Karmiloff-Smith's (1992) or Mandler's (1992) views of development with respect to the link between the two coexisting systems of knowledge: The conceptual system is not built through a redescription process.

Another notable exception to the idea that early behavioral competencies reflect implicit knowledge is provided by dynamic theories of development (e.g., Thelen & Smith, 1994). These theories strongly argue against any symbolic or computational view of cognition, claiming that our mind does not contain any representation or internal symbol. Perception, action, and cognition are considered as three undissociable facets of the activity deployed by any living organism in its environment. This activity is context-bound and continuously determined by both the environment's and the body's properties. Activity is defined by complex nets of relations established between a moving body in a specific environment, and cognition is necessarily embodied, distributed, and activity-driven. In this perspective,

development relies on self-organizing processes of active living systems, and not on any redescription or abstraction process, basically because there is nothing to redescribe! Indeed, in the dynamic approaches, the notion of explicit knowledge is rejected like the notion of implicit knowledge, insofar as this knowledge is thought of as grounded in internal symbols. Symbolic thought is the result of the creation of external symbols for these authors. More precisely, activity can be described as symbolic thought when it operates on external symbols created by previous active exchanges with the environment. In summary, the very notion of internal symbolic activity, either implicit or explicit, is dismissed. We postpone a comparison of this approach to ours to the final section of this chapter.

The Challenge

Our initial line of reasoning was that, due to the fact that implicit learning mechanisms seem, a priori, highly relevant to developmental phenomena, theories of development should provide some support to our challenging view of implicit learning, and notably, should support our rejection of the widespread notion of implicit knowledge. However, it turns out that the notion of implicit knowledge, notwithstanding some exceptions, finds a large echo in modern cognitive views of development. Note that the problem cannot be solved by arguing that the same term conveys different meanings in the two research contexts. On the contrary, the mainstream of the literature on implicit learning and of the literature on development confers the same general properties to implicit knowledge, namely, that it underlies initial behavioral adaptation and that it is closely related, in terms of its content, to knowledge that is available through introspection (this last point is made clear in the developmental literature by the assumption of a redescription of one form of knowledge into the other). Overall, this situation seemingly undermines the plausibility of our view. However, another possibility has to be explored, namely, that both the early behavioral mastery in children, and the subsequent emergence of explicit knowledge about the world, can themselves be reinterpreted along the same lines as the laboratory data on implicit learning in adults.

Our proposal is that the concept of implicit knowledge in the developmental literature, central to both nativist and constructivist approaches, stems from the same fundamental bias that has plagued implicit learning research for years, namely a misrepresentation of the source of the behavioral change. Briefly, our claim is that the construct of implicit knowledge, consisting of unconscious representations, becomes useless when one considers that improved performance of subjects, adults or children, is not grounded in an internalization of the structural properties of the environment.

In the next sections, we tackle the question of early behavioral competencies because most developmentalists appear to agree on the fact that these competencies rely on implicitly instantiated knowledge. As discussed above for Karmiloff-Smith's (1992) model, two types of early behavioral competence can be distinguished. The first type is linked to the functioning of the basic predispositions of the processing system. This type of behavioral competence exists at birth or soon after birth and embeds innate implicit knowledge. The second type is the result of learning through data-driven processes, as described by Karmiloff-Smith (1992) and Mandler (1988), and embeds acquired implicit knowledge. The first of the two next sections is devoted to a discussion of infants' predisposition of the processing system, and the second section is concerned with acquired behavioral competencies, particularly those revealed by habituation paradigms.

THE EARLY ABILITY TO PARSE THE WORLD

Clearly, infants' behavior is testimony of an ability to segment continuous sensory input into discrete objects. Likewise, the ability to segment a continuous speech stream into meaningful linguistic units appears unquestionable. Most developmental psychologists or psycholinguists postulate that children's ability to parse sensory input into physically or linguistically relevant units is possible because there exist innate constraints and domain-specific knowledge (Bower, 1979; Karmiloff-Smith, 1992), assumptions (Markman, 1990), presuppositions or intuitive theories (Spelke, Breinlinger, Macomber, & Jacobson, 1992) about the structure of the world.

Our concern is to assess whether the hypothesis of innate implicit knowledge is needed to account for infants' behavioral competence. Our skepticism stems from the fact that the phenomenon of parsing is observed in laboratory situations of implicit learning where the arbitrariness of the material makes unrealistic the postulate of innate theoretical presuppositions about its structure. In this context, as argued above, the segmentation of material into structurally relevant units may be explained within a very parsimonious framework involving only elementary associative processes.

Our objective is to assess whether this framework is able to account for developmental phenomena as well.

The application of associative learning theory to child development is a priori justified because the postulated mechanisms have been shown to be ubiquitous along the ontogenetic and phylogenetic scales. Of course, some adaptations are warranted. For instance, the primitives of the system will no longer be letters, but, for instance, spatially oriented features. However, there are some deeper problems. For example, in artificial grammar learning, the number of possible units is limited because subjects' attention is oriented, via instructions, toward the primitive letters. In real life, infants may capture unrelated componential aspects of the environment, such as a sound frequency, with the orientation of a segment of a visual display in a single attentional focus. Under these conditions, the formation of relevant units looks like a serendipitous task indeed.

Our proposal is that the apparent problem raised by the unmanageable number of possible units in infants' environment is solved by considering more carefully the idea that units are formed by the concurrent attentional processing of a few primitives. The point is that infants' attention is captured by an array of stimuli sharing specific properties. One of these properties, for instance, is novelty (e.g., Kagan, 1971). If, at a given moment, several primitives are new for the infants, it is highly probable that they are processed conjointly in the attentional focus, hence forming a new unit. If several primitives are new for a subject, then they have a high chance to become components of the same meaningful unit. This same line of reasoning may be followed with respect to movement. It is well-established that infants' attention is drawn by a moving display (e.g., Bronson, 1982; Haith, 1978; Vinter, 1986). If several elementary features move concurrently, they have a high chance to be attentionally processed by infants and to belong to the same real object (of course, many objects do not move; however, it may be argued that the relative movement due to eye displacement in a 3-D visual field generalizes the phenomenon).

The same logic may be applied to the segmentation of the world into objects, the segmentation of the linguistic input into words, and the object/word mapping. To illustrate the latter issue, let us consider an example inspired from a question raised by Karmiloff-Smith (1992, p. 40). When an adult points toward a cat and says "look, a cat," how can the child pair the word *cat* with the whole animal, rather than, say, with the cat's whiskers, the color of the cat's fur, or the background context? The conventional response to this question consists in hypothesizing that children have assumptions about the mapping between words and their referents. For instance, Markman (1990) identifies three assumptions: the whole-object assumption, the taxonomic assumption, and the assumption of mutual exclusivity. Our account is far more simple and general. What is susceptible to becoming associated is what captures infants' attention, what is new and/or moving, for instance. Considering first the auditory input, *cat* is presumably newer than *look*, because look has been associated with many contexts before, so it is highly probable that cat, rather than look, enters into the momentary attentional focus. On the other hand, it is also highly probable that infants' attention is focused on the animal, which moves as a whole, rather than on any of its parts or other elements of the context, which are presumably both more familiar and motionless.

Of course, the process of mapping as described above may fail sometimes. The infant may be quite familiar with cats and surprised by the color russet of the fur of this specific cat. We predict that, in the latter case, infants would mismap the world cat with the color russet. It is worth noting that in real world settings this situation may be infrequent because adults tend to spell out what is presumably the most novel to infants and, more generally, what they infer to be infants' present object of attention. On the other hand, errors of mapping do occur during language development. What is needed therefore is not a theory predicting a perfect mapping from the outset but a theory able to predict the final achievement. Associative theory is precisely adapted to distinguish signals from noise. In general, the correct mapping will be the final outcome because infants will hear cat for animals that are not russet and will hear *russet* for animals that are not cats.

To summarize, data and theories from the implicit learning literature suggest a new account of infants' basic competencies. Recall that conventional accounts rely on the notion of domain-specific implicit assumptions or theories about the world. In our opinion, children's ability to code the world into meaningful units requires assumptions or presuppositions no more than the ability of infants to rest on the ground instead of floating in the air requires an assumption about gravity. In the latter case, subjects' behavior is constrained by physical mechanisms, whereas in the former case, subjects' behavior is constrained by physiological and associative mechanisms. Postulating assumptions about the world is irrelevant in both cases. The subjective units are the perceptual, phenomenal results of associative processes operating at the physiological level. The only innate properties of the system we assume is that attentional processes are driven by a few stimulus features, such as novelty or movement. Given the adaptive role of these properties, it is highly probable that they have been selected for by evolution.

EARLY INFERENCES ABOUT THE WORLD

In our view, there is indeed a redescription of knowledge, albeit in a sense very different from the one argued for in Karmiloff-Smith's (1992) model. Instead of children redescribing their early implicit knowledge into explicit knowledge, it is scientists who redescribe children's late explicit knowledge into (imagined) early implicit knowledge. In this section, our objective is to illustrate this general claim by discussing various examples of early behavioral mastery reported by Karmiloff-Smith, which illustrate, according to the author, the implicit phase postulated in her model. As a first target, we selected studies showing that infants possess knowledge about the properties of the physical world, dealing successively with object substance and object permanence. Then, we will focus on another type of knowledge displayed by older infants, which is related to the distinction between animates and inanimates. Finally, we will discuss a last example of implicit knowledge analyzed by Karmiloff-Smith, pertaining to the principle of gravity. For each of these examples, we begin describing a foundational experiment and the conventional interpretation of its results. Then, we show that a simpler alternative explanation is available in each case, which makes the postulate of implicit knowledge superfluous. The reader should be aware that this part of the chapter is clearly speculative, insofar as we propose alternative explanations without providing direct empirical support for them. However, some concrete suggestions for empirical testing will be offered.

Object Substance

A series of experiments by Spelke and her collaborators (1992) aimed at showing that 4-month-old infants have an implicit theory about the fact that an object cannot pass through another one. Infants were first habituated to the view of a ball falling on a supporting surface, as shown in Figure 15.2a. Then, the infants were shown either an event congruent with the laws of physics, in which the ball also falls on a supporting surface but in a different location, or an event not congruent with the laws of physics, in which the ball falls on the same surface as in the habituation trial, but after

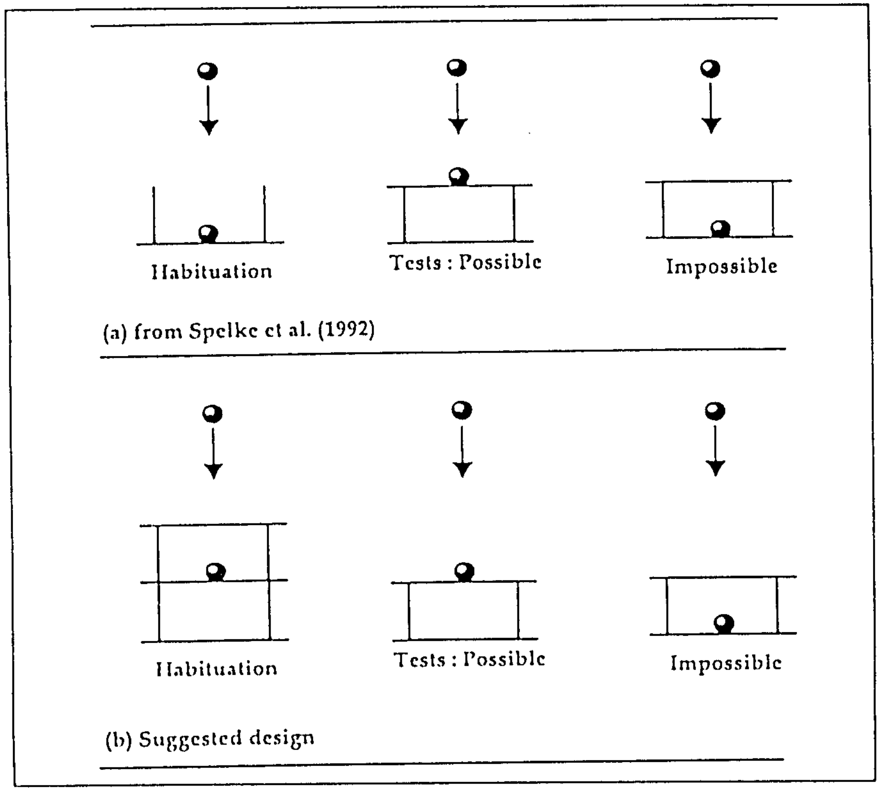


Figure 15.2. (a) Design of the Spelke et al. (1992) experiments, aimed at showing that 4-month-old infants have an implicit theory about the fact that an object cannot pass through another one. (b) Suggested design, intended to validate our alternative interpretation (see text for explanations).

falling through another potential supporting surface (to make this actually possible during the experiment, the final phase of the fall was masked, and the masking screen was subsequently lowered). Although the final location of the ball was different, and hence capable of capturing interest in the possible event, infants looked longer at the impossible events in which the final position of the ball was the same as in the habituation trials. Spelke et al. concluded that the behavior of 4-month-old infants demonstrated their knowledge that one solid object cannot pass through another one.

Now imagine the behavior of infants during the test trials when the masking screen is lowered. Presumably, infants are looking for a ball. In

the possible-event condition, the ball is effectively the first object that appears. In the impossible-event condition, infants discover a new object (a blue surface; the previous floor was red). In Spelke et al.'s (1992) view, infants looked longer at the impossible event because they realized that the ball could not have crossed through the surface. In our view, the new surface draws attention because it is not the event expected on the basis of the habituation trials. This alternative interpretation is amenable to empirical tests. Figure 15.2b represents a case in which the two test events are the same as in Spelke et al., but infants are now habituated to an impossible event. The crucial difference is that infants are habituated to first discover a blue surface while the masking screen is lowered. Presumably, Spelke et al. would predict that infants look longer at the impossible test event, insofar as it violates a physical law (note that it is also more dissimilar to the habituation event if one considers the absolute spatial location, which is the similarity criterion used by Spelke et al.). In contrast, our prediction is that infants would look longer at the possible event because the first encountered object is no longer an empty surface (despite the fact that the final location of the ball is the same as in the habituation trials).

Our proposal is that infants form a perceptual representation of the habituation event in which the lowering of the masking screen reveals either the ball or a blue surface. Then, they react to the test display as a function of its similarity with the habituation display. If the habituation event is possible, as in Spelke et al.'s (1992) experiments, infants look longer at the impossible test event. If the habituation event is impossible, infants should look longer at the possible test event. There is no theory about the world here guiding infants' behavior, only a presumably short-lived effect due to familiarity with a specific display. Note that the hypothesis that inspection duration of the test event is due to its degree of similarity with the habituation event rather than to whether this event violates some physical law or not, finds support in the fact that, as is apparent in the figures of Spelke et al.'s article, the difference in looking time virtually disappears after the very first test trial. The very same criticism can be applied to all experimental studies provided in Spelke et al. that investigate infants' knowledge of a variety of physical laws.

Object Permanence

As a second example, let us consider another well-known series of experiments (Baillargeon, Spelke, & Wasserman, 1985). In these experiments,

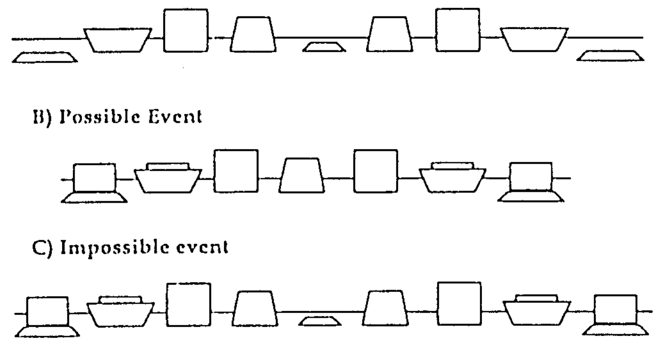


Figure 15.3. Schematic representation of what infants really saw in the Baillargeon et al. (1985) experiments, aimed at showing that 4- and 5-month-old infants have an implicit theory about some properties of physical objects, notably about their permanence (from Baillargeon et al., 1985; see text for explanation).

infants are habituated to the view of a screen moving back and forth through a 180-degree arc as shown in Figure 15.3a. Then, a solid box is placed behind the screen, preventing the complete rotation of the screen. Four and 5-month-old children are exposed to a series of possible or impossible events. For the possible events (Figure 15.3b), the screen was rotated until it reached the box (i.e., about 120 degrees), then it moved back to its initial position. The whole cycle lasted about 8 seconds. For the impossible events (Figure 15.3c), the screen completed a full 180-degree arc, covering the normal location of the box, which was no longer presented. Then, the screen moved back to its initial position, making the box visible again. The whole cycle lasted about 12 seconds. The reasoning of Baillargeon et al. (1985) was the following:

> If infants understood that (1) the box continued to exist, in its same location, after it was occluded by the screen, and (2) the screen could not move through the space occupied by the box, then they should perceive the impossible event to be novel, surprising, or both. (pp. 195-196)

In line with this prediction, infants looked longer at the impossible events than at the possible events. The authors concluded that infants as young as

5 months of age endow objects with some permanence and also realize that solid objects do not move through the space occupied by other solid objects.

Our point is that infants' performance may be explained when neither the first nor the second of Baillargeon et al.'s (1985) conditions are met. As evidenced by a comparison of Figures 15.3b and 15.3c, it suffices that infants looked longer at the more variable display than at the less variable one. When the possible event was cycled, infants saw a screen that occluded a motionless box repeatedly. When the impossible event was cycled, infants saw a screen that left visible the box only half of the time. It is highly probable that infants looked longer at the impossible event because the box appeared and disappeared while it was hidden by the screen, whatever the physical possibility of the scenario. An experimental setup testing our alternative hypothesis is easy to conceive, but it may be more economical to realize that this alternative hypothesis is supported every time a mother plays peek-a-boo with her baby.

The Animate/Inanimate Distinction

According to Karmiloff-Smith (1992), 12-month-old infants have implicit knowledge of the distinction between animates and inanimates. This claim is grounded in the results of a series of experiments by Mandler and Bauer (1988), in which, for instance, infants were simply placed in front of toys comprising animals and vehicles. Infants did not touch the toys randomly but instead manipulated, for example, a series of vehicles, then a series of animals. Of course, the infants were unable to verbalize anything about what they were doing. Another series of observations, with 3- and 4-year-old children by Gelman (1990), shows that when children become able to state verbal criteria, they separate animate from inanimate as a function of whether the movement of the target object is endogenously driven or requires an external agent. The problem is one of assessing whether the distinctive touching pattern of young infants is grounded in the same knowledge that is revealed when older children are questioned, the only difference being the format, implicit or explicit, of the representation. According to Karmiloff-Smith, the answer is positive because the source of movement is the only feature that could account for the early behavioral pattern, given that Mandler and Bauer (1988) took great care to control some aspects of perceptual similarity between the two categories of objects.

We argue that Karmiloff-Smith's notion of early implicit knowledge is a theorist's redescription of the later explicit knowledge, instead of its genuine precursor. There is no evidence that the touching patterns of infants are grounded in their knowledge that inanimate objects, in contrast to living beings, require an external agent for moving. Moreover, there is no evidence that children have acquired any knowledge about a general distinction between the two categories. The only justified inference from the empirical data is that infants, on average, perceive two specific animals or two specific vehicles as more similar to each other than an animal and a vehicle. This may be accounted for in multiple ways. For instance, one may suppose that infants first focus on the toys that have eyes. This entails that they pick up a series of animals in which eyes are clearly visible. Then, they may become interested in the presence of wheels on some toys, and hence manipulate for some time a series of vehicles that have wheels, and so on. This explanation does not require that the successive features on which infants focus are really definitional features of the categories, that is, are both present in all the exemplars of a category and absent in all the exemplars of the other. The only postulates required are that infants are interested in some aspects of the toys, that these aspects change over time, and that there are more aspects in common within a (experimenter-defined) category than between categories.

The Principle of Gravity

As a final illustration, we selected a series of experimental studies carried out by Karmiloff-Smith (1992) that provide, according to her, "a nice illustration of children's passage from behavioral mastery to verbally stateable theories" (p. 84). In these studies, children had to balance a series of parallelepipedic blocks on a narrow support. Some blocks were structurally homogeneous such that they balanced at their geometric center. Some other blocks, although apparently identical to the former ones, were filled with lead at one end, and thus their gravity center no longer matched their geometric center. Briefly, 4- and 5-year-olds moved every block along the support until it balanced by using the proprioceptive feedback about the direction of fall. They were in no way perturbed by the blocks with lead. Six and 7-year-olds placed every block at its geometric center. Doing so, they failed to balance asymmetrical blocks, which they pushed aside after a few unsuccessful trials. Eight to 9-year-olds succeeded in balancing each block, regardless of whether they were symmetrical or asymmetrical.

In Karmiloff-Smith's interpretation, implicit knowledge underlying the early behavioral adaptation is redescribed into two successive theories, the first focusing on the geometric center, which accounts for both successes and failures of 6- to 7-year-olds, and the second focusing on the gravity center, which accounts for the good performance of older children. By contrast, in our view, there is no continuity in the sources of the behavior, despite the fact that younger children behave as the older ones (at least on the very crude criterion that they balanced the blocks). We contend that initial mastery is the product of a trial-and-error procedure, which supports the existence of some pieces of (presumably explicit) knowledge, but which does not require an implicit theory of gravity. This claim finds support in the following pseudo-experiment. Suppose that the experimental arrangement is modified in such a way that the location for balancing the blocks is no longer their gravity center. (For example, the experiment is run in an orbital station, and the gravitational forces are replaced by magnetic forces, or some other fiddle). We would predict, as probably everyone would agree, that young children would be as successful as they are in natural contexts precisely because they solve the problem by a trial-and-error procedure. If children's performance were grounded in implicit knowledge of gravity, it should be impaired relative to an unfiddled situation. We fail to see how performance could be mediated by the implicit knowledge of a law without being affected when this law no longer applies.

Note that we do not question that children are able to form explicit theories. Rather, our claim is that these theories are built from a variety of sources, including earlier pieces of explicit knowledge, instead of being a redescription of the implicit knowledge presumably embedded in early procedural mastery. This theory building may be partially grounded in memory of past episodes. For instance, children may infer a general principle from the stored conscious representations of a number of previous trials in which the blocks turned out to balance when they were supported in their geometric center. Trial-and-error procedures may reveal some information about the structure of the world, but there is no sense in claiming that the success of a trial-and-error strategy is due to tacit knowledge about the structure of a task. A trial-and-error procedure provides information that can be used in a subsequent inferential process, but in the same way as the information provided through external sources. There is no privileged, intrasubject transfer of knowledge from an implicit to an explicit recipient.

To summarize, we have challenged the widespread idea that implicit knowledge underlies early behavioral adaptation by showing that the notion of implicit knowledge is not needed to account for several findings that have been construed as support for this notion. In each case, children's behavior can be accounted for by an acquired sensitivity to different aspects of the experimental situations, making them sensitive to factors such as the degree of novelty or the variety of displayed events. Of course, we do not deprive children of any competence. We assume that infants perceive eyes of animals, wheels of vehicles, a ball falling on a floor, a box, a screen, and so on, instead of their being the receptors of an unstructured beam of sensory excitations. Recall that we accounted for these primitive competencies in associative terms in the previous sections.

FINAL CONSIDERATIONS

Toward an Integrative View of Development and Adult Implicit Learning

In developmental psychology, the implicit knowledge assumption stems from the observation of a quite remarkable adaptation of the child to structured situations. The reasoning is that early behavioral adaptation necessarily requires processing of the structural properties of the situations and results from an internalization of these properties. This leads to the formation of knowledge, the content of which corresponds to a representation of the internalized properties of the situations, and the nature of which is implicit because it cannot be elicited independent of the context or the routine in which it is embedded. This view finds a large echo in mainstream theories of implicit learning in adults. However, in this chapter, we have proposed a different explanation in which the notion of implicit knowledge has no place.

The developmental literature we scrutinized shows that experimental data put forth in support of the notion of implicit knowledge can be conveniently reinterpreted within the same framework that led to reinterpretation of the data from adult implicit learning experiments. Of course, this demonstration can only have a provisional status. Our argument is undermined by the fact that we focused on a limited sample of the experimental literature. Although our analysis included some of the foundational experiments in current cognitive developmental psychology, many other studies were not considered. A larger synthesis is currently in progress in our laboratory (Vinter & Perruchet, 1997). Perhaps more important, our alternative interpretation is mostly speculative, given that we provided no direct experimental support. Clearly, further empirical studies are needed before firm conclusions may be drawn. We suggested several experimental situations that may ultimately provide one possible basis for empirical testing.

Pending further evidence, it is worth providing the lineaments of a view that is potentially relevant for both development and adult implicit learning and that excludes the notion of implicit knowledge. The starting point for this view is that some features of a situation that the subject is exposed to capture attentional processes. The features capturing attention may be fairly different for newborn and older humans. Presumably, some properties such as movement and novelty trigger infants' attention as a consequence of hard-wired, innate mechanisms. In children and adults, attention is increasingly dependent on subjects' background knowledge, which itself is dependent on previous learning. However, the consequences of attentional processing are always the same. They consist in the parsing of incoming information into units. Because these units are composed of the primitive features that are processed conjointly in the attentional focus, they determine the conscious, phenomenal apprehension that subjects have of the material.

When the incoming information is structured or repeated, which is often the case when it comes from the natural environment, the composition of the subjective units is progressively modified in order to provide a conscious coding of the material, which becomes increasingly relevant to the structure of the task. This crucial phenomenon is a mandatory, automatic consequence of attentional processing. The reason is that attention triggers the action of unconscious associative mechanisms that have remarkable power to provide an optimal parsing of the material. The behavioral changes observed in infants, children, and adults are the results of this progressive formation of subjective units that map the structurally relevant components of the world. In this view, implicit acquisition phenomena, whatever the age at which they occur, may be conceived of as progressive changes in the conscious perceptions and representations of the world toward a better mapping with the world's deep structure through the action of intrinsically unconscious associative mechanisms.

In this conception, there is no longer any place for the notion of implicit knowledge. There are only unconscious processes shaping conscious experience. We alluded above to some models of development in which, in contrast to the dominant view, the notion of implicit knowledge is also dismissed. This is especially the case for dynamic theories (e.g., Thelen & Smith, 1994). These theories strongly argue against any symbolic or computational view of cognition, claiming that our mind does not contain any representation or internal symbol. Activity is described as symbolic thought when it operates on external symbols created by previous active exchanges with the environment. Thus, the existence of internal, implicit knowledge is negated, but the existence of explicit knowledge is rejected as well. Noteworthy, our account departs radically from the dynamic conceptions in the sense that we fully acknowledge the relevance of the notion of explicit knowledge. This notion is embodied in that of sensory-based or internal subjective units, which are at the core of our account. More generally, explicit knowledge is revealed through the existence of higher-level forms of thought, proceeding through conscious operations upon internal representations, although, as discussed below, this issue needs to be elaborated further.

Higher-Level Reasoning and Conscious Thought

Any theory of development and learning must ultimately integrate an account of higher forms of thoughts, including the formation of abstract knowledge about the properties of the world whose existence is constitutive of adults' representations. The current literature on implicit learning is virtually mute on this point. Most of this literature is devoted to the demonstration of dissociations between implicit and explicit forms of knowledge. The emergence of any form of explicit knowledge, whether specific or abstract, is only considered a potential bias. By contrast, the literature on child development on which we have focused in this chapter provides an integrative view. Karmiloff-Smith's (1992) theory postulates that explicit knowledge about the properties of the environment is a progressive redescription of the implicit knowledge embedded in the performance. Likewise, Mandler (1992) suggests that conceptual propositional knowledge arises from a redescription of conceptual image-schemas, which themselves are the results of a redescription of perceptual schemas. The attractive aspect of such frameworks is that they introduce a link between the early behavioral adaptation to a task and the later formation of explicit knowledge about the properties of this task through the notion of implicit knowledge. Our reappraisal consists of showing that early behavioral adaptation is not grounded in implicit knowledge. However, insofar as this reappraisal may be considered successful, we are now faced with a question

that may be put forth crudely in the following terms: If explicit knowledge about the structural properties of the world does not come from its earlier, implicit counterpart, where then does it come from?

We suggest that there is no continuity between the early behavioral adaptations and the subsequent knowledge of the properties of the world. In the remainder of this chapter, we illustrate this proposal with an analogy, which may also shed further light on both our criticism of the notion of implicit knowledge and the gist of our alternative account. The analogy concerns the ability to localize sound in space. As is well-known, humans are able to state the direction in space of a sound-emitting object due to the processing of binaural cues. The binaural listener makes use of the physical differences in stimulation that arise between the two ears because of their separation in space. For instance, a sound source can be located, under some circumstances, on the basis of differences in the time of arrival of stimulation to the two ears of as little as .0001 seconds (e.g., Handel, 1989). The responsible mechanism is the precedence effect, which results in the neural activity produced by the first tone partially inhibiting the response to the later one. This mechanism is efficient because it exploits a specific property of the sound waves, namely their speed of propagation. However, everybody would probably agree, we presume, that it makes no sense to endow laypeople with some implicit knowledge of the speed of propagation of sound, nor with any other properties of sound waves that the auditory system exploits. The neural mechanisms embed no hidden form of knowledge that could be made explicit with further effort or time. The speed of propagation of sound waves was assessed by scientific investigations, proceeding through an analytical, rational approach. These investigations were not made simpler or different because the scientists localized sound themselves: They could have been performed by deaf scientists as well.

Let us imagine now that, instead of being due to innate mechanisms, the neural substrate of which is at least partially known, the ability to detect the localization of a sound is learned during infancy. This scenario is not completely fanciful. The fact that, although present at birth, the mechanisms of sound localization are subsequently adjusted to accommodate the increasing distance between the two ears, due presumably to concurrent visual information, supports the view that this kind of ability is not out of reach of learning mechanisms. Another indication is provided by the remarkable use of auditory information in spatial localization by blind individuals who have had an early visual experience in orientation prior to losing their sight

(Veraart & Wanet-Defalque, 1987). But the likelihood of our assumption is not essential to our argument: our point is only to assess the consequence of this assumption upon the interpretation of the phenomena. Although we have no privileged insight into Karmiloff-Smith's mind, we suggest that it would be in the spirit of her model to assert that improved sound localization testifies to the acquisition of some implicit knowledge about the properties of the sound waves. In keeping with the same logic, the subsequent explicit knowledge that some people acquire about the properties of sound waves could be construed as the product of a redescription process of this earlier implicit knowledge.

Our proposal is that the same conception may apply, whether the ability at hand is the end product of a hard-wired innate mechanism or results from implicit learning episodes. The product of the mechanisms implemented in the auditory system is nothing other than the conscious experience of sound localization. We suggest that the neural modifications following an implicit learning episode affect our conscious experience of the world in the same way as the hard-wired mechanisms located in the auditory system shape our conscious representation of the sound space. These mechanisms embed no hidden knowledge. Insofar as the notion of knowledge makes sense here, it is only from the observer's (or scientist's) point of view. One can pass all of one's lifetime trying to redescribe the actual reasons that make one perceive the direction of a sound and yet never obtain knowledge about the speed of sound waves or even about the very existence of sound waves. Likewise, any attempts to redescribe, for instance, gravity laws from the mechanisms triggering the adaptation of the human body to these laws, is doomed to fail. Abstract knowledge is in no way a redescription of knowledge internally stored; it is a genuine construction. Explicit knowledge about the properties of the world is due to the engagement of inferential problem-solving processes, operating on a database comprising the conscious componential representation of the situation, such as is provided by unconscious associative processes.

Summary

The dominant theories of implicit learning and the dominant theories of development share a common postulate, namely, that early behavioral adaptations are grounded in subjects' implicit knowledge bases. The goal of this chapter was to show that our previous reinterpretation of the data put forth in support of the concept of implicit knowledge in the implicit learning research area can be successfully applied to the developmental domain as well. We argue for a new integrative account of implicit learning and development in which implicit acquisition phenomena, whatever the age at which they occur, may be conceived of as progressive changes in the conscious perceptions and representations of the world toward a better mapping with the world's deep structure through the action of intrinsically unconscious associative mechanisms.

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