CHAPTER 6

Methods for studying unconscious learning

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Abstract: One has to face numerous difficulties when trying to establish a dissociation between conscious and unconscious knowledge. In this paper, we review several of these problems as well as the different methodological solutions that have been proposed to address them. We suggest that each of the different methodological solutions offered refers to a different operational definition of consciousness, and present empirical examples of sequence learning studies in which these different procedures were applied to differentiate between implicit and explicit knowledge acquisition. We also show how the use of a sensitive behavioral method, the process dissociation procedure, confers a distinctive advantage in brain-imaging studies when aiming to delineate the neural correlates of conscious and unconscious processes in sequence learning.

Introduction

With the recent development of brain-imaging methods, the study of consciousness tends more and more to be considered as a relatively easy problem that does not require any particular methodological approach. From this perspective, consciousness is merely viewed as another aspect of human cognition such as, for instance, motor action, memory, learning, or perception.

About 10 years ago, Chalmers (1995) proposed a distinction between hard and easy problems in the study of consciousness. According to Chalmers, the hard problem relates to studies aimed at understanding the relationship between brain activity correlated with awareness and the particular subjective experience that proceeds from this neural activity. The easy problems of consciousness are, among others, the conceptual and methodological issues faced by researchers studying the ability to report mental states, or the voluntary control of behavior. Chalmers claims that easy problems are those that seem accessible to the standard methods of cognitive science, i.e., they would be explainable in terms of computational or neural mechanisms, whereas hard problems resist these methodological and explanatory frameworks. In this view, and given the current development of brain-imaging techniques that allow for in-depth investigation of the neural correlates of higher-level cognitive processes, the search for the neural correlates of consciousness should belong to Chalmers’ easy problems.

In this chapter, however, we argue that functional brain-imaging approaches to the cerebral correlates of conscious and unconscious processes do not obviate the need for powerful behavioral methods as one is still confronted with the need to carefully determine the conscious versus unconscious character of the knowledge expressed in any task. We acknowledge that Chalmers’ distinction underlines important differences between first and third person aspects of consciousness that certainly involve different levels of conceptual complexity. It is, for instance, difficult to formulate an explanation of the relationship between a given

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stimulation and the corresponding subjective experience (e.g., the redness of red). It is comparatively easier to imagine how brain-imaging methods may constitute a powerful tool to differentiate between conscious and unconscious cognition. However, we will show that when one is trying to devise a sensitive and reliable methodological procedure to address this latter question, easy problems might turn out to be not so easy after all.

The definition of an accurate and sensitive methodological approach for differentiating between conscious and unconscious cognitive processes has always been a controversial issue. This is because there is no obvious way to find a proper measure of awareness in the absence of a satisfactory operational definition of the concept. How can one describe what it means for somebody else to be conscious of some knowledge? How can one measure the amount of conscious knowledge held by another individual? These questions have been fiercely debated across several domains of cognitive psychology, including the literature on implicit memory, learning, and perception. In this paper we will focus on implicit sequence learning, which is one of the most popular paradigms for studying unconscious learning.

**Sequence learning as an example of unconscious cognition**

In a typical sequence learning situation (see Clegg et al., 1998), participants are asked to react to each element of a sequentially structured and typically visual sequence of events in the context of a serial reaction time (SRT) task. On each trial, a stimulus appears at one of several locations on a computer screen. Subjects are instructed to press a spatially corresponding key as fast and as accurately as possible. Unknown to them, the sequence of successive stimuli follows a repeating pattern (Nissen and Bullemer, 1987). Reaction times (RT) tend to decrease progressively with continued practice, but then dramatically increase when the repeating pattern is modified in any of the several ways (Cohen et al., 1990; Curran and Keele, 1993; Reed and Johnson, 1994). This suggests that subjects learn the repeated pattern and prepare their responses based on their knowledge of the sequence. Nevertheless, subjects often fail to exhibit verbal knowledge of the pattern — a dissociation that has led many authors to consider learning to be implicit in this situation.

As discussed elsewhere Cleeremans et al. (1998), sequence learning can be described as implicit in several different ways depending on whether one focuses on the acquisition or retrieval processes, or on the knowledge resulting from the learning episode. Here, we will focus on this latter aspect of implicit learning and discuss how one can establish the extent to which the knowledge acquired during the SRT task can be described as conscious or unconscious.

Recall, however, that the methodological and conceptual issues raised by this question are by no means limited to the implicit learning literature, and a fortiori to the sequence learning paradigm. Indeed, as previously pointed out by Goschke (1997), ever since the 1960s these same issues have also been the object of controversy in the subliminal perception literature (e.g., Ericksen, 1960; Holender, 1986).

**Dissociation studies**

Most studies aimed at demonstrating the existence of implicit knowledge have taken the form of dissociation experiments in which performance in an initial learning or exposure task — often considered as exclusively dependent on implicit processes — is compared with performance in a subsequent test task, which is assumed to give an index of participants’ conscious knowledge. According to this dissociation logic (Erdelyi, 1986), knowledge is implicit if performance exceeds baseline in the first task — indicating that learning took place — but is at chance in the test phase, suggesting that participants do not have conscious access to the knowledge that has been acquired.

Several different measures of conscious knowledge have been used in the sequence learning paradigm, each of them corresponding to a different operational definition of consciousness (see Table 1). In the following sections, we will examine these
separate procedures and compare their ability to provide accurate measures of consciousness.

### Verbal reports

Since awareness can naturally be described as an essentially private, first-person phenomenon, verbal reports and questionnaires have been used as the prior measurement method to estimate conscious knowledge. Accordingly, the initial claims for the existence of an implicit form of learning are based on reported dissociations between, on the one hand, a significant decrement in reaction time during the SRT task and, on the other, the inability of some but not all participants to report the regularities of the sequence (Willingham et al., 1989; Curran and Keele, 1993).

Several authors have recently argued that first-person methodologies constitute an essential way of understanding and measuring consciousness (Overgaard, 2001). However, while these methods might indeed capture gross and simple features of conscious experience (Chalmers, 1999), they might not actually be sensitive enough to provide an accurate measurement tool for dissociating between conscious and unconscious knowledge and furthermore for differentiating between the different features of conscious experience. For instance, although there is no doubt that sequence learning can be defined as conscious if participants are able to describe verbally the regularities of the training sequence, the opposite may not be true, i.e., a poor performance in questionnaire or verbal report tasks does not necessarily imply that learning was implicit.

From this perspective, Shanks and St. John (1994) have pointed out that verbal reports do not always satisfy the two criteria that they consider to be critical; the information and sensitivity criteria. According to the information criterion, the task used to measure conscious knowledge must tap into the same knowledge base upon which learning is based. Otherwise, learning could be described as unconscious not because participants are unable to access their knowledge consciously but simply because they are probed about irrelevant features of the training material that they did not need to process in order to perform the task. For instance, this might be the case in sequence learning studies in which participants are asked to report first- or second-order sequential regularities between successive elements, while zero-order information, such as variations in the frequencies of the sequence elements, are sufficient to account for RT performance.

According to Shanks and St. John’s (1994) sensitivity criterion, the test used to measure conscious knowledge must be sensitive to all of the relevant information. If this criterion is not met, unconscious influences on performance might be overestimated because some conscious knowledge remains undetected by the awareness test. There are several reasons to argue that verbal reports fail the sensitivity criterion and, therefore, do not constitute an adequate measure of awareness. Firstly, subjects might fail to report fragmentary knowledge held with low confidence. Secondly, in the case of verbal reports, performance and awareness tests implement very different retrieval contexts (Shanks and St. John, 1994). With respect to the sequence learning paradigm, none of the contextual cues that are available to support

### Table 1. Synoptic table of different operational definitions of consciousness and the corresponding tasks used to measure consciousness

<table>
<thead>
<tr>
<th>Operational definitions of consciousness</th>
<th>Measurements of conscious knowledge</th>
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<tr>
<td>Consciousness allows verbal access to the acquired knowledge</td>
<td>Verbal reports, questionnaires</td>
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<tr>
<td>Consciousness allows recollection of the acquired knowledge</td>
<td>Recognition and generation tasks</td>
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<td>Conscious learning allows control on the expression of the acquired knowledge</td>
<td>Direct and indirect tasks, inclusion and exclusion tasks</td>
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<td>Conscious learning is associated with the acquisition of meta-knowledge (i.e., participants know that they have learned something and that they are using this knowledge to perform a task)</td>
<td>Guessing judgment tasks, confidence judgment tasks</td>
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performance in the RT task (such as the visual presentation of the stimuli, the requirement of motor responses, and a sustained pace of responding) are available to support verbal reports.

It is possible to improve the sensitivity of the awareness test by using questionnaires that involve more specific queries about the relevant knowledge. However, the use of questionnaires impose conditions on the test phase that are rather different from those in the training phase. Many authors have therefore suggested that valid tests of awareness should involve forced-choice tasks such as recognition tasks. It has been argued that these are able to detect conscious knowledge left undetected by verbal reports or questionnaires (Willingham et al., 1989; Perruchet and Amorim, 1992; Frensch et al., 1994; Shanks and St. John, 1994; Shanks and Johnstone, 1998; Shanks and Johnstone, 1999).

**Forced-choice tasks**

In order to improve the sensitivity of the awareness test, forced-choice tasks (which implement retrieval conditions closer to the learning task itself) have been used to measure conscious knowledge. Under the assumption that consciousness allows recollection of the acquired knowledge, these tests have generally taken the form of generation or recognition tasks at the end of sequence learning. In a typical generation task, participants are requested to reproduce the training sequence themselves by pressing the key corresponding to the location of the next stimulus instead of reacting to the current target. In the recognition task, they are presented with a sequence fragment, and after reacting to each element as they did in the RT task (i.e., by pressing as fast and as accurately as possible on the corresponding key), are asked to identify whether or not the fragment was part of the training sequence. In sequence learning studies, forced-choice tests of conscious knowledge that prompt reproduction of the training sequence or differentiation of old and new sequence fragments have quite systematically indicated that participants were able to express a great deal of the knowledge they acquired in the SRT task (e.g., Perruchet and Amorim, 1992).

These results have frequently been interpreted as an indication of the conscious nature of sequence learning and have led into questioning the very existence of an implicit form of learning. However, others have challenged the assumption that generation or recognition performance depends solely on conscious knowledge (e.g., Jiménez et al., 1996). It is indeed true that these tasks involve the same type of retrieval conditions as the SRT task: participants have to react to visual stimuli by giving motor responses and, at least in the case of recognition tasks, at the same pace of responding. As a result there is little reason to believe that SRT tasks and awareness tests tap into different knowledge bases, and thus that implicit knowledge does not contribute to generation or recognition performance. Indeed, it has been shown that participants are able to reproduce the training sequence in a generation task even when they claim to guess the location of the next sequence element (Shanks and Johnstone, 1998). Furthermore, in a recognition task, subjects may tend to respond faster to old sequence fragments than to novel ones; recognition ratings may therefore reflect this improved feeling of perceptual and motor fluency rather than explicit recollection of the training material (see Perruchet and Amorim, 1992; Perruchet and Gallego, 1993; Willingham et al., 1993, for relevant discussion, Cohen and Curran, 1993). Performance in both recognition and generation tasks, rather than depending exclusively on conscious knowledge, is thus likely to depend on both implicit and explicit influences. By the same token, it must also be emphasized that sequence acquisition during the SRT task is itself likely to involve both implicit and explicit components.

In sum, forced-choice tasks are more prone to meet the information and sensitivity criteria than free reports or questionnaires. This improvement, however, is at the cost of the so-called *exclusive-ness assumption* (Reingold and Merikle, 1988), according to which the test of awareness must be sensitive *only* to the relevant conscious knowledge. Unfortunately, the most sensitive tests of awareness are also the most likely to be contaminated by implicit knowledge (Neal and Hesketh, 1997). The logic of quantitative dissociation has therefore been questioned by the argument that no task can
be used as an absolute test of awareness that would be both sensitive to all a subject’s conscious knowledge, and only to the relevant conscious knowledge. In other words, it is highly implausible that any task can be considered as “process-pure”. To further improve awareness tests, different solutions have been proposed to overcome this so-called “contamination” problem. These procedures, which we discuss in the following sections, were initially proposed in the fields of subliminal perception and implicit memory, and later applied to the domain of implicit learning.

**Subjective measures of awareness**

Cheesman and Merikle (1984) have introduced the notion of subjective and objective thresholds in subliminal perception. In a typical experiment, the task simply consists in identifying a series of visual targets that are briefly flashed on a computer screen. Perception is said to be under the subjective threshold when participants are able to identify the target at above chance performance while stating that they did not perceive it consciously. Perception is said to be under the objective threshold when identification is at chance. Hence, perception is under the subjective threshold when a subject does not know that he knows the identity of the target, or in other words, when he has no meta-knowledge. Perception is under the objective threshold when the target has simply not been perceived. According to Cheesman and Merikle, perception is unconscious when it is under the subjective threshold.

Dienes and Berry (1997) have suggested the application of the same threshold criteria to the study of implicit learning. In this framework, the acquired knowledge would be over the objective threshold when performance in a forced-choice task is above baseline. Learning could be described as unconscious if knowledge remains under the subjective threshold at the same time, i.e., if participants claim to respond at chance in the forced-choice task used to measure conscious knowledge. This procedure can indeed be extremely fruitful when attempting to disentangle conscious and unconscious knowledge given that, as discussed above, both types of knowledge can subtend performance in a forced-choice task.

Dienes et al. (1995), see also Dienes and Perner (1999), have described two criteria that make it possible to demonstrate unconscious knowledge acquisition. The first one, the guessing criterion, corresponds to the criterion used by Cheesman and Merikle: knowledge is unconscious when performance is above chance while participants claim to perform at chance. The second one, the zero-correlation criterion, is met when confidence levels and performance rates are uncorrelated.

These two procedures have seldom been applied in sequence learning studies. In one experiment, using the guessing criterion after the generation task, Shanks and Johnstone (1998) asked participants to say whether they felt that they were reproducing the training sequence or that they respond randomly. Only 3 out of 15 participants felt that some fragments of the sequence were familiar and part of the training sequence. When these three subjects were excluded from the analysis, generation performance was still above chance level. In another experiment of the same study, these authors applied the zero-correlation criterion by asking participants to rate how confident they were in their generation performance on a scale ranging from 0 to 100. They observed that the experimental subjects reproduced more of the training sequence than a control group presented with a random sequence during training. However, some of the experimental subjects did not show a higher level of confidence than the control participants.

These results seem to suggest that learning was at least partly unconscious. However, Reingold and Merikle (1990) have insisted that subjective measurement of unconscious knowledge must be interpreted with caution given that subjective measures of awareness depend on the participants’ interpretation of the task instructions. Indeed, participants might essentially give a larger interpretation to the term “guess” than the experimenter. Accordingly, Shanks and Johnstone have argued that, in their first study, participants’ subjective experience might have become confused and discontinued during the generation task, leading them to consider that they were guessing the
next location when this was not actually the case. A similar interpretative problem may arise in Shanks and Johnstone’s second study, which used the zero-correlation criterion; in this study participants were able to evaluate their confidence level based not only on the accessibility to consciousness of the acquired knowledge but also on how much they believed was expected from them. For instance, a given subject might have underestimated his level of confidence because he assigned a high level of expectancy to the experimenter.

To summarize, the criticisms previously laid against verbal reports may also be applied to subjective measures because, in both cases, subjects have to decide themselves whether they have access to some knowledge or whether they were able to perform a task effectively. Subjective measures of awareness should therefore be combined with other measurement methods that do not raise the same problems of interpretation. In the following sections, we describe two such methodological frameworks that consider, as a starting point, that conscious knowledge supports intentional control.

**Comparison between direct and indirect tasks**

Given that no task can be considered as a process-pure measure of awareness, Reingold and Merikle (1988) (in the field of subliminal perception) have proposed to compare the relative sensitivity of direct and indirect tasks to conscious influences. In an indirect task, participants are not explicitly required to make a response based on relevant information (e.g., the identity of a visual target in a perception study or the sequential regularities in a sequence learning study). Conversely, in a direct task participants have to respond on the basis of this information. In Reingold and Merikle’s framework, both tasks must be matched as much as possible in all characteristics, such as retrieval context and demands. It is only the instructions that must differ. This method is based on the hypothesis that both conscious and unconscious knowledge may influence performance in direct and indirect tasks. In addition, it is also posited that conscious influences will not be higher in the indirect task than in the direct task given that participants are required to respond on the basis of explicit knowledge in the latter but not in the former case. Therefore, if the indirect task detects some knowledge that is left undetected by the direct task, this knowledge can be considered as unconscious. This procedure has later been applied to different domains such as subliminal perception (Greenwald et al., 1995), unconscious memory (Merikle and Reingold, 1991), and sequence learning (Jiménez et al., 1996).

In the study of Jiménez et al., the sequence of stimuli was produced according to the rules of an artificial grammar. In 15% of the trials, the stimulus generated by the artificial grammar was replaced by another one that violated the rules of the grammar. The relevant information was thus the difference between the grammatical and ungrammatical sequential transitions. In this context, the RT difference between regular and irregular trials in the SRT task can be considered as an indirect measure of sequence learning since participants do not have to respond on the basis of this information: they merely have to indicate the location of the current target irrespective of its grammatical or ungrammatical status. As a direct measure of learning, Jiménez et al., this time, used a generation task in which participants were required to reproduce the grammatical transitions of the training sequence. By comparing the performance in both tasks, they were able to show that some knowledge about the sequence was exclusively expressed in the indirect task but not in the direct generation task. For some sequential transitions, participants responded faster for grammatical stimuli than for ungrammatical stimuli. However, there was no accompanying increase in the production of the corresponding regularities in the generation task — leading the authors to conclude that this knowledge was unconscious.

A limitation of this comparative method is that the indirect measure must always be more sensitive than the direct measure in order to show unconscious influences on performance (Toth et al., 1994). Some results, however, suggest that this might not always be the case in sequence learning (Shanks and Johnstone, 1998; Perruchet et al., 1997). In the next section, we describe another methodological framework, which compares subjects’ performance on
two tasks that differ only with respect to their instructions: this procedure makes it possible to circumvent this particular issue of sensitivity.

The process dissociation procedure

Similar to Reingold and Merikle’s framework, the process dissociation procedure (PDP), initially described by Jacoby (1991) in the field of implicit memory research, is formed from the idea that consciousness subsumes intentional control. By contrast, it is assumed that unconscious knowledge influences performance independently from, or against, task instructions. According to the logic of the procedure, conscious and unconscious influences can be estimated from the comparison of two situations in which both these influences either contribute to performance — the inclusion task — or are set in opposition — the exclusion task. The inclusion and exclusion tasks differ only with respect to their instructions. In the context of sequence learning, consider for instance a generation task performed under inclusion instructions. Participants are told to produce a sequence that resembles the training sequence as much as possible. To do so, they can either explicitly recollect the regularities of the training sequence, or they can guess the location of the next stimulus based on intuition or familiarity. Hence, under inclusion instructions, both conscious (C, e.g., recollection) and unconscious (U, e.g., intuition) processes can contribute to improve performance (C + U). Now consider the same generation task, but this time performed under exclusion instructions. Participants are now told to generate a sequence that differs as much as possible from the training sequence. Conscious and unconscious influences are now set in opposition, for the only way to successfully avoid producing familiar sequence elements is to consciously know what the training sequence was and to produce something different. Continued generation of familiar elements under exclusion instructions would thus clearly indicate that generation is automatically influenced by unconscious knowledge (U). Within the PDP, an estimate of conscious influences (C) can therefore be obtained by computing the difference between inclusion and exclusion performance and an estimate of unconscious influence (U) can be derived from the amount of which exclusion performance exceeds baseline.

The PDP has also raised many controversies. However, these are mainly concerned with the specific measurement model used to obtain the quantitative estimate of the implicit influences on performance. Different models that reflect the hypothetical relationship between both conscious and unconscious influences have indeed been proposed (see Richardson-Klavehn et al., 1996). A complete discussion of this issue is largely beyond the scope of this paper. However, it has been proposed that this measurement problem can be circumvented by focusing on inclusion and exclusion performance only (Neal and Hesketh, 1997).

Goschke (1997) using the PDP in this way, reported that a secondary tone-counting task impaired explicit knowledge acquisition but left implicit learning unaffected. With a similar procedure, Destrebecqz and Cleeremans (2001) have shown that slowing the pace of the SRT task by increasing the response-to-stimulus interval (RSI) tends to improve explicit learning. Other authors have put forward the notion that the pace of the SRT task only influences the expression of knowledge rather than learning per se (Willingham et al., 1997) or does not influence the quality of sequence learning, the acquired knowledge being always conscious whatever the pace of the SRT task (Wilkinson and Shanks, 2004). It must be noted, however, that the importance of timing factors has been emphasized in theoretical accounts of sequence learning (Keele et al., 2003) and specifically in relation to the conscious or unconscious nature of learning (Stadler, 1997). Recent studies are also in line with the idea that conscious processes require more time than unconscious ones (Rabbitt, 2002). In the next section, we present additional data supporting this hypothesis.

In search of the neural correlates of conscious and unconscious processes

As evidenced in the above discussion, the identification of the neural correlates of conscious and
unconscious processes crucially requires the use of sensitive behavioral methods that overcome potential methodological flaws. Capitalizing on previous behavioral results, we have adapted the PDP in a brain-imaging study in order to identify the neural correlates of conscious and unconscious sequence processing (Destrebecqz et al., 2003; Destrebecqz et al., submitted). In two $^{15}$O Positron Emission Tomography (PET) studies, volunteers were trained on the SRT task (15 blocks of 96 trials using a repeated 12-element sequence) before being scanned during three consecutive inclusion and three consecutive exclusion blocks. During training, the pace of the SRT task was manipulated by modifying the value of the RSI, i.e., the amount of time that elapses between the motor response and the onset of the next target. Participants were either trained with a standard 250 ms RSI (RSI250 condition) or with a RSI reduced to 0 ms (RSI0 condition). In this latter RSI0 condition, each target was immediately replaced by the next one, reducing the likelihood of participants developing conscious expectancies regarding the identity of the next element (Destrebecqz and Cleeremans, 2001).

Inclusion scores were higher than exclusion scores in both RSI0 and RSI250 conditions, indicating that participants had gained conscious sequence knowledge in both conditions. Inclusion scores, however, were higher in the RSI250 condition than in the RSI0 condition. By contrast, exclusion scores (that reflect the production of the training sequence against the instructions) were higher in the RSI0 condition than in the RSI250 condition, suggesting that unconscious influences were higher in the former than in the latter condition. The mean difference between inclusion and exclusion scores was higher in the RSI250 than in the RSI0 condition indicating that control over behavior was improved in the former condition and, therefore, according to the PDP logic driven by explicit, conscious learning.

At the neuroanatomical level, we reasoned that those brain areas in which variations of regional cerebral blood flow (rCBF) closely follow the variations of the generation scores obtained at each scan in the inclusion or the exclusion condition should be part of the neural network that subtends conscious and unconscious contributions to performance.

Firstly, to identify the neural correlates of conscious sequence processing, we looked for brain regions in which the correlation between rCBF and generation score was higher in the inclusion than in the exclusion task, irrespective of the duration of the RSI. Indeed, inclusion scores are thought to reflect both conscious and unconscious contributions \((C+U)\) to performance, whereas rCBF variations related to the exclusion scores only reflect unconscious contributions \((U)\). The interaction \(\frac{(C+U)−U}{C} = C\) effect should therefore indicate the brain areas that specifically subdend conscious contributions to performance. Results showed that the anterior cingulate/medial prefrontal cortex (ACC/MPFC) supports the conscious component of sequence processing in both the RSI250 and RSI0 conditions (see Fig. 1C).

Secondly, to identify the neural correlates of unconscious sequence knowledge, we looked for brain areas in which the correlation between rCBF and exclusion scores was modulated by the training condition, i.e., was higher in the RSI0 than in the RSI250 condition (exclusion results suggested that knowledge was more implicit in the RSI0 than in the RSI250 condition). This analysis revealed that caudate activity supported implicit contributions to performance in the sequence generation task (see Fig. 1B). This result is in line with previous data showing the involvement of the caudate nucleus during implicit sequence acquisition in a probabilistic version of the SRT task (Fig. 1A; Peigneux et al., 2000).

PET data analysis also evidenced a tight coupling between activity measured in ACC/MPFC and in striatum in the exclusion task in the RSI250 condition, in which learning was essentially explicit, whereas the activity of these regions was uncoupled in the RSI0 condition, in which implicit influences were stronger. These results suggest that the ACC/MPFC exerts control on the activity of the striatum during sequence generation in the former but not in the latter condition — indicating that implicit processes can be successfully controlled by conscious knowledge when learning is essentially explicit.
Concluding remarks

In this paper, we have described the numerous intricacies of the arguments surrounding a theoretical dissociation between conscious and unconscious knowledge, as well as the various methodological solutions that have been proposed to address these questions. We have shown that each of these proposed solutions refers to a different operational definition of consciousness, and have presented empirical examples of sequence learning studies in which these procedures have been used to differentiate between implicit and explicit knowledge acquisition. Altogether, these studies indicate that a single measure of awareness is unable to offer a precise assessment of the extent to which knowledge has been consciously acquired during a learning episode. Only a few studies, however, have systematically applied several awareness tests at the same time in order to measure correlations among those tasks or to show possible dissociations between them (e.g., Shanks and Johnstone, 1998; Destrebecqz and Cleeremans, 2003).

Interestingly, some proposed models of consciousness — the global workspace framework (Baars, 1988; this volume) — predict systematic associations between all the different possible measures of awareness. According to Dehaene and Naccache (2001), for instance, once a piece of information becomes conscious, it becomes globally available to a variety of processes including categorization, memorization, evaluation and intentional action. Their hypothesis is that this global availability constitutes conscious subjective experience.

However, other reports have shown that learning can, under some conditions, result in knowledge that is under intentional control but not systematically and simultaneously associated with meta-knowledge (Destrebecqz and Cleeremans, 2003). Such learning would thus be described as conscious with respect to the PDP but as unconscious with respect to the subjective threshold criterion. Based on results from connectionist simulations, it has also been suggested that these behavioral dissociations can be accounted for within a framework in which conscious access is viewed as resulting from continuous, gradual changes in a single dimension involving “quality of representation”. This dimension designates several properties of memory traces, such as their relative strength, their distinctiveness, or their stability in time (see Cleeremans and Jiménez, 2002; Cleeremans, forthcoming). Depending on training conditions, the quality of the developed representations varies along a continuous dimension and

Fig. 1. Brain correlates of conscious and unconscious knowledge. (A) Sequence acquisition in a probabilistic SRT task: increase cerebral blood flow (CBF) in the caudate nucleus was observed only when subjects' performances demonstrated implicit knowledge of sequential regularities (Peigneux et al., 2000). (B) Implicit sequence generation after practice to the SRT task: caudate CBF correlates more with exclusion scores when learning is essentially unconscious (i.e., higher correlation in the RSI0 ms than the RSI250 condition; Destrebecqz et al., submitted). (C) Explicit sequence generation after practice to the SRT task: CBF correlations in ACC/mesial prefrontal cortex with generation scores is modulated by the instruction condition (i.e., higher in the inclusion than in the exclusion condition) both in the RSI0 and RSI250 conditions (Destrebecqz et al., 2003). (See text for details.) All activations are displayed at uncorrected $p<0.001$, on subjects’ averaged T-1 weighted MRI.
determines the extent to which memory traces can influence performance in different awareness tests. Subjective measures would, in this framework, entail higher quality representations than procedures based on intentional control.

In the same perspective, Marcel (1993) conducted a visual target detection study in which participants were asked to respond in three different ways: verbally, by blinking, or by pressing a key. When the three responses were required at the same time, they often tended to be dissociated. Participants could, for instance, claim to detect the target in one modality but not in another. Marcel further noted that subjective confidence levels varied consistently between response modalities. Other reports, in the field of unconscious perception, have shown that stimulus recognition can occur in the absence of stimulus detection either when chromatic flashes (Rollman and Nachmias, 1972) or when words (Merikle and Reingold, 1990) are presented. In other words, participants may be able to recognize a color or a word at a better level of accuracy than the accuracy level produced by chance even when they claim that they did not previously detect its presence. According to Merikle and Reingold (1990, p. 582), however, this pattern of results may be related to differences between tasks in bias or in criterion (i.e., the minimum level of certainty that is necessary for a participant to say that some stimulus has been presented). As noted by Merikle and Reingold, dissociations are indeed expected if criterion placement changes independently across the different tasks used to measure conscious knowledge.

At first sight, these dissociation results might seem to be at odds with global workspace theories of consciousness. However, further research is needed in order to determine whether these dissociations merely reflect sensitivity differences between the tasks used to measure awareness or whether they represent more fundamental differences between the nature of the mental representations and the neural mechanisms that subserve conscious processing in those tasks. We believe that the understanding of the cognitive and neural mechanisms subsuming conscious processes will benefit from the simultaneous use of different measurement procedures. An accurate theory of consciousness will have to explain the conditions under which all of these measures are associated or dissociated.

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