Conscious versus unconscious learning of structure

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1. Introduction

The ways we come to learn about the structure of complex environments is intimately linked to the conscious-unconscious distinction. Indeed, Reber (1967, 1989) argued that we could acquire unconscious knowledge of some structures we could not readily consciously learn about because of their complexity. Some authors agree there are two modes of learning distinguished by their conscious versus unconscious phenomenology (e.g. Scott & Dienes, 2010a). Others at least agree there are striking differences in phenomenology in different learning situations. For example, Shanks (2005), who does not accept there is such thing as unconscious knowledge, nonetheless notes that when he himself performed a standard implicit learning task that he found that "trying to articulate my knowledge, even only moments after performing the task, seem[ed] to require a Herculean effort of mental will that yield[ed] only the sketchiest useful information. (p. 211)" By contrast, in yet other learning situations, knowledge can be readily described as it is being applied. The everyday example of natural language makes the contrast between these phenomenologies stark. We all learnt the main grammatical constructions of our native language by about age five without even consciously knowing there was a grammar to be learnt. And as adults we still cannot describe all the rules we spontaneously use. Yet when we learn a second language as an adult we may spend considerable time memorising rules of grammar. The two methods of learning feel very different and produce different results. By suitably defining conscious versus unconscious we can describe the difference in phenomenologies. And that difference may well be a marker of different mechanisms of learning. Indeed, the difference in phenomenology is so striking that the distinction was constantly reinvented before it became part of an established literature, despite behaviouristic tendencies in psychologists to avoid the conscious versus unconscious terms (e.g. Broadbent, 1977; Hull, 1920; Lewicki, 1986; Phelan, 1965; Reber, 1967; Rommetveit, 1960; Smoke, 1932). Thus, the starting point for a definition of conscious versus unconscious should be one that picks out the real life examples that motivate the distinction,

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and not one that makes the distinction evaporate. Just as phenomenologically unconscious learning seems especially powerful when we consider language or perceptual motor skills (Reed, McLeod, & Dienes, 2010), so many things are learnt only consciously (e.g. special relativity). Often what is interesting is the fact we can or cannot learn a structure unconsciously (or consciously) – not just whether we can or cannot learn it. Thus, it is vital for learning researchers to have a means for determining the conscious or unconscious status of knowledge, suitably defined. Only then can we experimentally explore whether the phenomenologies mark qualitatively different, if possibly interacting, learning mechanisms – and also isolate those mechanisms on a trial by trial basis.

In this chapter I present a methodology for determining the conscious status of structural knowledge. First, I offer a definition of what an unconscious mental state is. Then I will use the definition to motivate a method of measuring the conscious-unconscious distinction. The method can be applied separately to different knowledge contents, specifically to "judgment" knowledge and "structural" knowledge, which will be defined. Next I review evidence that when the method is used to separate conscious from unconscious structural knowledge it isolates different learning systems (thus, the method shows its scientific worth). Finally, I present recent experiments showing its application (to cross cultural differences and to learning language-like structure in the lab).

2. What is unconscious knowledge?

I will take conscious knowledge to be knowledge one is conscious of (cf. Rosenthal, 2005; also Carruthers, 2000). This may sound like a tautology, but it is not, as we now see. How are we ever conscious of anything, say, of a dog being there? Only by either perceiving that the dog is there or thinking that it is there; that is, only by having some mental state that asserts that the dog is there. Likewise, to be conscious of knowledge we need to have a mental state that asserts that the knowledge is there. In other words, a higher-order mental state (a mental state about a mental state) is needed to be conscious of knowing. To establish that knowledge is conscious one must establish that the subject is in a metacognitive state of knowing about knowing: and this claim is not a tautology. Simply showing that a person knows about the world (for example, by accurately discriminating states of the world) will not do for determining whether the knowledge is conscious. Establishing that there is knowledge is just a precondition for establishing whether it is conscious or not. But establishing that there is knowledge clearly does not establish whether the knowledge is conscious or unconscious. In sum, accepting that: *conscious knowledge is knowledge one is conscious of*, is to accept that: *establishing the conscious status of knowledge requires establishing the existence of a metacognitive state* (see Rosenthal, e.g. 2005, from whom this argument has been adapted to the case of knowledge). The argument can be put concisely: To be conscious of X requires a mental state about X; knowing is a mental state; thus, being conscious of knowing requires a mental state about a mental state.

Some argue that metacognition is one thing and a state being conscious is another; *being aware that one is in a mental state* is 'introspective' or 'reflective' or 'higher order' consciousness, which is not necessary for a mental state to be simply conscious (Block, 2001; Dulany, 1991; Seth, 2008). While it seems odd to say that a mental state is conscious when a person is in no way conscious of being in that state, there is no point quibbling excessively over terminology. For those who argue that there is higher order consciousness separately from a mental state being conscious, they can simply translate what I am calling "conscious knowledge" into "reflectively conscious knowledge" or whatever their favourite term is. The scientific problem I will be addressing is to determine whether the fact of whether or not one is aware of one's knowledge (or can be when probed) can distinguish qualitatively different types of knowledge or learning mechanisms. Once this point is accepted, a lot of heat in the implicit learning literature can be side stepped. For example, Dulany (1991), a critic of the existence of unconscious knowledge, nonetheless accepts as obvious that we can be in a mental state without being aware that we are (e.g. p. 109). And knowing without being aware of knowing is exactly what I am calling unconscious knowledge. Having some match to everyday use is the reason for using a term at all, and the definition of conscious knowledge as 'the knowledge of which one is conscious' in no way stretches the everyday use of the word. On the other hand, allowing knowledge to be conscious that a person sincerely denies having probably does stretch normal usage. In the end however, the test is not armchair argument or exact every day usage, but whether the definition is useful in conjunction with a theory in predicting experimental findings (Dienes, 2008; Dienes & Scott, 2005; Dienes & Seth, 2010a; Merikle, 1992; Seth et al., 2008). And that is what we will explore: Does the definition pull itself up by its bootstraps by being scientifically useful? First, we need to find a way of operationalising the definition.

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3. How can we measure awareness of knowing?

To establish that knowledge is conscious requires establishing the existence of a metacognitive state (Cleeremans, 2008; Dienes, 2008; Lau, 2008). Thus, establishing that a person can make a discrimination about states of affairs in the world ("worldly discrimination") with forced choice discrimination or recognition tests establishes only that there is knowledge, but not that it is conscious. How could we determine whether or not a person is conscious of their knowledge? One way is to ask them to freely report what they know about the domain. The logic of this method is that a person will only report as facts about the world what they think they know. Indeed, free report has been used as a test of conscious knowledge ever since the word "implicit learning" was coined by Reber (1967) to mean learning that produces unconscious knowledge.

Reber (1967) introduced the artificial grammar learning task as a task for investigating implicit learning. He used a finite state grammar to generate strings of letters. Subjects memorised such strings without being told that the strings were rule governed. After 5–10 minutes subjects were told of the existence of a set of rules, but not what they were. Subjects could classify new strings as grammatical or not, with 60–70% accuracy depending on materials. However, at the end of the experiment people found it hard to describe the rules of the grammar, and Reber took this as evidence that subjects lacked conscious knowledge. Such "post task free report" has been widely used to determine the extent of people's conscious knowledge. But it is not a compelling measure because it involves subjects' attempts to recall their thinking some time after it happened (Ericsson and Simon, 1980). Reber and Lewis (1977) asked people to report their reasons after each classification instead of at the end of a set of trials, clearly an improvement, and a source of valuable information about the person's conscious knowledge. Nonetheless, the method is still problematic.

Berry and Dienes (1993, p. 38) isolated two potential problems with any measure of conscious knowledge. The first is "simply not asking for the same knowledge that the subject used to classify" and the second problem is of "differential test sensitivity" (the two problems also highlighted by Shanks and St John, 1994). In terms of the first, if people did not use general rules to classify but instead analogy to recollected training items, they may not report their actual source of grammaticality judgments if they believe the experimenter is only interested in hearing about rules (Brooks, 1978; Jamieson & Mewhort, 2009). Alternatively, people may not report using the experimenter's rules if specifically asked about them, because they used a correlated but different rule (Dulany, 1962). This problem can be overcome by suitable instructions, but it does highlight the care that needs to be taken in collecting free reports (Ruenger & Frensch 2010). In terms of the second problem, people may hold back on reporting knowledge if they are not completely confident in it. Why risk stating a rule that might be wrong? Thus, free report might easily underestimate the amount of conscious knowledge that a person has.

A method that deals with both these problems is eliciting confidence after every judgment. Any knowledge the participant is conscious of using as knowledge, no matter what its content, should be reflected in the participant's confidence. Further, using confidence ratings has an advantage over free report in that low confidence is no longer a means by which relevant conscious knowledge is excluded from measurement; rather the confidence itself becomes the object of study and can be directly assessed on every trial. Indeed, Ziori and Dienes (2006) provided empirical evidence for the greater sensitivity of confidence-based methods over free report in detecting conscious knowledge.

The simplest confidence scale is for the subject to report 'guess' if she believes the judgment had no basis whatsoever, and 'know' if she believes the judgment constituted knowledge to some extent. If on all the trials when the person says 'guess' nonetheless the discrimination performance is above baseline, then there is evidence that the person does have knowledge (performance above baseline) that she doesn't know she has (she says she is guessing). This is unconscious knowledge by the *guessing criterion*. If a person's knowledge states are conscious, she will know when she knows and when she is just guessing. In this case, there should be a relation between confidence and accuracy. Thus, a relation between confidence and accuracy indicates conscious knowledge and zero relation indicates unconscious knowledge by the *zero-correlation criterion* (Dienes, Altmann, Kwan, & Goode, 1995).

Confidence can also be elicited by various methods of gambling. Persaud, McLeod, & Cowey (2008) asked people to wager high or low on each grammaticality decision. Subjects were told that if their decision was wrong they would lose the amount of the wager and if their decision was right they would win that amount. Low wagers can be taken to reflect low confidence and high wagers higher confidence in one's grammaticality decision. The problem with wagering is that it is subject to loss aversion: A person may wager low even though they have some confidence in their decision, but they do not want any risk of losing the higher amount of money. Indeed, Dienes and Seth (2010b) showed empirically that high-

(V9 5/4/12 14:42) WDG-LCB (155mm×230mm) TimesNRMT 1382 Rebuschat pp. 337–364 1382 Rebuschat_11_dienes (p. 341)

low wagering was sensitive to loss aversion. Further, Dienes and Seth introduced a loss-free gambling method for measuring confidence to eliminate the confounding effect of loss aversion. On each trial subjects made two decisions. First was a grammaticality decision. Second was a choice of one of two cards the subject had just shuffled. One card had a reward printed on the back, the other was blank. Next the subject made a choice between the two decisions. For whichever decision they chose, if they got it right, they won the reward. If they got it wrong nothing happened. Thus, subjects should always be motivated to bet on their grammaticality decision if they had the slightest confidence that it was right: loss aversion is irrelevant. Nonetheless, subjects sometimes chose to bet on the transparently random process rather than their own grammaticality decision; and on those trials subjects were still about 60% correct on their grammaticality decision. This is unconscious knowledge by the guessing criterion. Further, subjects were more accurate on the grammaticality decision when they bet on that rather than the transparently random process: This is conscious knowledge by the zero correlation criterion. Thus the method confirmed that artificial grammar learning involves a mix of trials, some on which subjects are aware of knowing grammaticality, and some on which they are not. The use of no-loss gambling helps subjects appreciate what we want them to understand by "guess". "Guessing" on the grammaticality decision means one expects to perform no better than a random process. In general, eliciting confidence by means of gambling enables measuring the conscious status of knowledge in young children (Ruffman et. 2001) and even some non-human primates (Kornell, Son, & Terrace, 2007).

A more indirect measure of awareness of knowing is to ability to control (Jacoby, 1991: the "process dissociation procedure"). The logic of this method is that if one is aware of one's knowledge, one can control its use, if so instructed. Fu Dienes and Fu (2010) showed that in one implicit learning task (the SRT or serial reaction time task) when people said they were guessing in predicting the next element they also had no control over the use of knowledge: When asked to produce the next element according to the rules they no more tended to produce rule-governed completions than when asked to produce the next element such that it violated the rules. Further when people had some confidence they also had some control. So awareness of knowing as measured by confidence and as measured by control went together in this case. However, control and conscious knowledge do not always go together. Dienes et al. (1995) and Wan, Dienes, and Fu (2008) showed that people could control which of two grammars to use while believing they were completely guessing. That is, unconscious knowledge can produce control, and thus the presence of control does not definitively indicate the knowledge was conscious. Nonetheless a lack of control (under self paced conditions) is a good indicator of unconscious knowledge: If a person reliably produces grammatical choices when told to pick only ungrammatical items, without time pressure, it is often good evidence that the person is not actually aware of grammaticality (see Destrebecqz & Cleeremans, 2001; Fu, Fu, & Dienes, 2008; and Rohrmeier, Fu, & Dienes, submitted, for examples).

In sum, to measure awareness of knowing that an item belongs to a category, the method with least ambiguity is no-loss gambling. Nonetheless, verbal confidence, where "guess" has been defined to subjects as meaning equivalent to the outcome of a random process, also behaves well and is not correlated with loss aversion (Dienes & Seth, 2010b). Measures based on control can be informative, but may produce ambiguous findings.

4. Judgment versus structural knowledge

A person has conscious knowledge that p when they are aware of knowing that p, where p is any proposition. Mental states with different contents are different mental states. 'Knowing that p' is different from 'knowing that q' if p and q are different. Being conscious of knowing that p thus entails that we know that we know specifically p. Being aware of knowing q does not make knowledge of p conscious. Corollary: A good methodological rule whenever a claim is made about a state or process being conscious or unconscious is to always specify the content said to be conscious or unconscious (cf. Dienes & Seth, 2010c). For example, implicit memory does not normally involve any unconscious knowledge per se, something that becomes clear as soon as one tries to specify the content of the knowledge involved. The presentation of a word may strengthen the connections between the letters in the part of the cortex that codes words, making the word a more likely completion to a stem. The knowledge applied in stem completion is what letters can follow other letters and there is no reason to think this is unconscious when the person completes the stem. Further there is no reason to think the person has any knowledge, conscious or unconscious, that the word was presented in the experiment (cf. Dulany, 1991). So implicit memory is not a case of unconscious knowledge. Implicit learning, by contrast, does involve unconscious knowledge.

What are the knowledge contents involved in an implicit learning experiment? When a person is exposed to a domain with some structure they often acquire knowledge about that structure (e.g. Reber, 1989; Gebhart, Newport, & Aslin, 2009). The knowledge might be of the conditional probabilities of successive elements, of allowable chunks and their probabilities of occurrence, of what letters can start a string, of allowable types of symmetries and their probabilities, of particular allowed sequences, and so on. Let us call all this knowledge 'structural knowledge' . For any of this knowledge to be conscious, one would have to be aware of having specifically that knowledge. For example, to consciously know that "An M can start a string" one would have to represent specifically "I know that an M can start a string". Such a metacognitive representation makes a particular piece of structural knowledge conscious, namely the knowledge that M can start a string. In a test phase a subject may make judgments about whether a presented item is grammatical or not: Whether this string is grammatical, or whether this item can occur next in the sequence. Structural knowledge is brought to bear on the test item to form a new piece of knowledge, for example, that this item has the structure of the training items. Let us call this knowledge 'judgment knowledge'. That is, when a subject makes a judgment that p, then the judgment knowledge has content p. The structural knowledge is whatever other knowledge the person had that enabled the judgement. For example, if a subject judges that "MTTVX is grammatical" the judgment knowledge is that "MTTVX is grammatical" and the structural knowledge the person may have used are things like "An M can start a string", "VX is an allowable bigram", and "MTTVT is an allowable string".

What knowledge do the methods of the last section determine the conscious status of? When a person makes a judgment followed by a confidence rating, the expressed confidence is in the judgment. Thus, confidence ratings – whether verbal reports, high-low wagering, or no-loss gambling – determine the conscious status of judgment knowledge. Similarly, Jacoby's method of measuring control, as applied to implicit learning (Destrebecqz & Cleeremans, 2001; Dienes et al. 1995; Fu Fu & Dienes, 2008; Fu Dienes & Fu, 2010; Jiménez, Vaquero, & Lupiáñez, 2006; Wan et al. 2008) measures ability to control making a judgment, and hence measures the conscious status of judgment knowledge. If a person is confident that this string is grammatical, they are aware of knowing this string is grammatical, but that does not mean they are aware of the structural knowledge that enabled that judgment. Similarly a person may, because they consciously know that this item is grammatical, be able to choose that item OR another one if instructed according to Jacoby's methods, but that control over the judgment does not mean the person consciously knows why it is grammatical.

The conscious status of judgment knowledge does not completely determine the conscious status of structural knowledge. Consider our knowledge of our native language. Our structural knowledge can be largely unconscious. Yet we may be sure that a given sentence is ungrammatical even if we do not know why: Conscious judgment knowledge, unconscious structural knowledge. But if a key divide between different learning mechanisms is between conscious and unconscious structural knowledge rather than between conscious and unconscious judgment knowledge then we need a method for measuring the conscious status of structural knowledge rather than just of judgment knowledge.

Free report does measure the conscious status of structural knowledge. But as mentioned, free report has its problems. Dienes and Scott (2005) devised a simple method for measuring the conscious status of structural knowledge that deals with these problems (see also Fu, Dienes, & Fu, 2010; Guo et al., in press; Rebuschat, 2008; Scott & Dienes 2008, 2010b,c; Wan et al., 2008; Chen et al., in press). After every judgment subjects indicate what the basis of the judgment was according to a set of attribution categories: random, the judgment had no basis whatsoever; intuition, it had some basis but the subject had no idea what it was; familiarity, the decision was based on a feeling of familiarity but the subject had no idea what the familiarity itself was based on; recollection, the basis was a recollection of a string or strings or part(s) of the strings from training; and rules, the basis was a rule or rules that the subject could state if asked. Assuming the subject's judgments are above baseline for each attribution, then: random attributions indicate that both judgment and structural knowledge were unconscious; intuition and familiarity attributions indicate that judgment knowledge was conscious but structural knowledge was unconscious; and recollection and rules indicate both judgment and structural knowledge were conscious. Thus, to measure the amount of unconscious structural knowledge one can pool together random, intuition and familiarity attributions, and to measure the amount of conscious structural knowledge one can pool together the recollection and rules attributions. If one wanted to compare conscious and unconscious judgment knowledge, random attributions could be compared with intuition and familiarity: the conscious status of structural knowledge has been controlled because it is unconscious for each of these attributions.

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One criticism of free report is that subjects may believe the experimenter only wants to hear about rules and not specific recalled exemplars, or some types of rule rather than another. The attributions in contrast do not presuppose any particular form of conscious structural knowledge beyond it being classifiable as rules or recollections. And if the subject does not want to report a rule that might be wrong, that is fine: We do not actually ask people to report their rules, just indicate if they have one. Further, confidence can be elicited independently of the felt basis of the judgment: If people used rules that they felt they were just guessing, this can be indicated by a rules response and a separate confidence rating (Scott & Dienes, 2008). The attributions are recorded trial by trial, and can even be given by the very same button press as indicates the classification judgment (Dienes, Baddeley, & Jansari, submitted), so forgetting should not be an issue. The method, though simple, prima facie deals with many problems that face measures of conscious knowledge. But the acid test of its worth is whether it contributes to explaining empirical findings in a theoretically motivated way. Subjects may simply pick arbitrarily amongst the attributions according to whim or momentary bias. What evidence is there that they reflect anything interesting?

5. Have subjective measures of the conscious status of structural knowledge proved their mettle?

First we need to situate conscious and unconscious knowledge within a theory. The theoretical claims should be sufficiently broad that they don't depend on a theory so idiosyncratic that few would wish to strongly associate the conscious-unconscious distinction with it; but sufficiently precise that some predictions can be made. Relatedly, the theory should go beyond defining conscious versus unconscious, but rather introduce properties that differ between the conscious and the unconscious in an empirical, contingent way rather than a conceptual way, so that the properties can be empirically tested as differing between conscious and unconscious knowledge. (If the properties were conceptually associated with the conscious-unconscious – i.e. necessarily part of our proposed concept of that distinction – one could not *test* whether the conscious-unconscious was associated with those properties.) So here is a theoretical context that tries to satisfy these constraints.

5.1. The theoretical context

Prototypical unconscious knowledge is the structural knowledge embedded in the weights of a connectionist network (which could effectively learn exemplars, abstractions or both: Cleeremans & Dienes, 2008). Typically such knowledge does not need manipulation in working memory to be applied; it just needs activation running through it. Why should such knowledge empirically be unconscious? Because there is no reason why such knowledge should be input to a device that forms higher order thoughts, or awareness of knowing specific contents. For example, if accurate thoughts about one's mental states are located in a specific location (e.g. the mid dorsolateral prefrontal cortex according to Lau & Passingham, 2006), the values of synaptic weights in other brain regions would not normally be input to that location, only patterns of activation would be.

A connectionist network can classify by an overall goodness-of-fit signal, that we postulate corresponds to a feeling of familiarity (Dienes, Scott & Wan, 2011), such a feeling communicating the existence of unconscious structural knowledge to more general conscious mechanisms (the function of ”fringe feelings” according to Mangan, 1993, and Norman, Price, Duff, & Mentzoni, 2007). For example, in a test phase, if part of a string feels more familiar than another part, this can be used to form a conscious rule about why that might be so.

Prototypical conscious structural knowledge is knowledge formed by hypothesis testing: By the consideration of hypotheticals understood as such, and also by the use of recollection. Why should such knowledge be associated with awareness of knowing? First, the knowledge would be represented as a pattern of activation rather than a pattern of connection strengths – but this alone is not enough. Importantly, hypotheses, understood as such, need to be represented in a format which explicitly marks the distinction between reality and possibility, a level of explicitness Dienes and Perner (1999, 2002) argued was close to explicitly marking knowledge as knowledge. That is, the step from representing a tested hypothesis as such to conscious knowledge is thus a short one. Recollection intrinsically involves representing oneself as remembering, and hence involves awareness of knowing (Perner & Ruffman, 1995; Searle, 1983). Further, hypothesis testing (and recollection) usually require the use of working memory. It is plausible that information in working memory is generally available to different processing modules in the brain, including any that have the function to form accurate higher order thoughts.

(V9 5/4/12 14:42) WDG-LCB (155mm×230mm) TimesNRMT 1382 Rebuschat pp. 337–364 1382 Rebuschat_11_dienes (p. 347)

As connectionist networks become adapted to particular domains, they learn to detect structures in new instances in that domain most easily according to the structures already learned and their prior probabilities. More generally, we postulate that people will unconsciously learn those structures most easily in the lab which have a high prior probability of being relevant in that domain, strictly statistical or not. Hypothesis testing can become fixated and ruled by prior probabilities too; but it can also make flexible jumps that can be useful or lead one systematically astray.

The model proposed is a dual process one – learning can be based on a mechanism that acquires unconscious structural knowledge or a mechanism that acquires conscious structural knowledge. Dual process models have been criticised in the implicit learning literature, and single process models proposed, possessing the virtue of simplicity (e.g. Shanks, 2005; Cleeremans & Jiménez, 2002). These single-process authors use connectionist networks where all knowledge of the grammar is embedded in the weights. The "single process" aspect of the models are that they could, if a metacognitive component were added, model both conscious and unconscious judgment knowledge with a single learning device that acquires unconscious structural knowledge (see Pasquali, Timmermans, & Cleeremans, 2010, for an integrated connectionist model of learning and metacognition). However, the models still leave a necessary distinction between conscious and unconscious structural knowledge, as they only model the latter (compare Shanks & St John's, 1994, distinction between exemplar-based and rule-based learning). Thus, the single process proposals of Cleeremans and Shanks are in principle consistent with the framework developed here. Thus, the framework is sufficiently broad, it should capture the intuitions of a large number of workers in the field.

5.2. The evidence

That is the theoretical context, showing that given a particular conceptual approach to the conscious – unconscious knowledge distinction (viz conscious knowledge is knowledge one is conscious of), there are further properties, based on theoretical speculation, that should be empirically associated with conscious versus unconscious knowledge. Does the method of measuring conscious status by the structural knowledge attributions classify accurately often enough that it helps identify qualitatively different types of knowledge that fit in with this theoretical framework? We now consider the evidence. (Note that we do not require the attributions *always* classify accurately – no instrument in science does that – just that it classifies accurately enough we can get on with the science, refining the measurement process as we go.)

1. Conscious unlike unconscious structural knowledge typically requires manipulation in working memory for the knowledge to be applied to a new test item. Thus engaging executive resources at test should interfere specifically with conscious structural knowledge. Dienes and Scott (2005; experiment 2) found just such a dissociation, where random number generation at test interfered with the application of conscious structural knowledge but not at all for unconscious structural knowledge. (Interfering with perceptual rather than executive resources interferes with both conscious and unconscious structural knowledge, Tanaka et al. 2008; Eitam, Schul, & Hassin, 2009; Rowland & Shanks, 2006, as would be expected if the input to a connectionist learning device were degraded.)

2. When unconscious knowledge is formed for a domain consisting of simple statistics over well established perceptual units, it should be largely accurate. Conscious knowledge may also be partially correct, but when it is wrong it will lead to the same mistake being repeated – the repeated application of a partially correct rule makes one both consistently correct and consistently incorrect (cf. Reber, 1989, from which this prediction is derived; see also Sun, 2002, whose conscious and unconscious systems embody a similar principle). Indeed, Dienes and Scott (2005; experiment 1) found that when people gave unconscious structural knowledge attributions, they did not systematically misclassify strings (i.e. if a string was misclassified one time it may be classified correctly the next). On the other hand, when people gave conscious structural knowledge attributions, if they made an error in classifying a string, the error was likely to be repeated.

Likewise, Reed, McLeod and Dienes (2010) found that in a perceptual motor domain where a simple rule exists for avoiding/creating interceptions between us and other objects, a rule that no doubt has been crucial to survival in the evolutionary past, the knowledge of the rule was unconscious as revealed by confidence ratings. Further, conscious knowledge was systematically wrong, misled by its own flexibility in considering all sorts of possibilities of how things might be.

3. As the postulated differences between conscious and unconscious structural knowledge reflect qualitatively different learning mechanisms, differences between the mechanisms should not be reducible to a single dimension, such as confidence (cf. Tunney 2007). Indeed, recent work by

Andy Mealor at the University of Sussex showed that the reaction times for unconscious rather than conscious structural knowledge attributions were different (as it turned out, longer). Reaction times were also correlated with confidence, such that the lower the confidence the longer the RTs. So could the difference in RTs between conscious and unconscious knowledge be simply due to a difference in confidence? The answer is no: Once confidence was partialed out, the reaction time difference between conscious and unconscious structural knowledge remained.

The output of the unconscious mechanism is often not consciously experienced as anything, or at least as not the output of a learning mechanism (see Dienes, Scott & Wan, 2011). But often it is experienced as a feeling of familiarity which people can rate. Scott and Dienes (2008) and Wan et al. (2008) found a greater relation between rated feelings of familiarity and classification when people said they were using feelings of familiarity as their attribution than when they used other unconscious attributions (Dienes, Scott & Wan, 2011). Thus, the attribution of familiarity is not given arbitrarily. When feelings of familiarity are conscious, we can make the following prediction:

4. If people have consciously worked out some aspects of structure, they will have more knowledge relevant to making a classification than is contained in their feelings of familiarity. This is just what Scott and Dienes (2008) found. In a standard artificial grammar learning task, where we know people acquire some accurate conscious structural knowledge (Reber & Lewis, 1977), familiarity ratings of each item predicted grammaticality judgments for both conscious and unconscious structural knowledge, but judgments based on conscious structural knowledge had additional discriminative ability above and beyond rated familiarity (unlike judgments based on ‘familiarity’ attributions; cf Scott & Dienes, 2010c).

Thus, the attribution method shows its mettle by not simply *classifying* different types of knowledge but *identifying* a real divide in nature, separating out knowledge qualitatively different in ways expected based on theory. There is also additional evidence that people do not hand out the attributions arbitrarily. Riccardo Pedersini working at the University of Sussex found that Galvanic Skin Response was different for correct and incorrect answers on an artificial grammar learning task. The difference was significant for each attribution category, and of a very similar magnitude for the unconscious structural knowledge attributions amongst themselves and for the conscious structural knowledge attributions amongst themselves – but strikingly different between conscious and unconscious structural knowledge attributions[1]. In sum, the different phenomenology associated with conscious and unconscious structural knowledge corresponds to objective differences in the properties of the knowledge. More work remains to be done, of course: For example, are the structural knowledge attributions useful in separating knowledge with different time constants of decay (cf. Allen & Reber, 1980), or knowledge differentially related to IQ (cf. Gebauer & Mackintosh, 2007) or other individual difference variables (cf. Scott & Dienes, 2010a)? To what extent does eliciting the ratings change what type of knowledge is used?

Unconscious knowledge as revealed by this method is substantial, replicable, and occasionally more powerful than conscious knowledge (Scott and Dienes, 2010c; Reed, McLeod and Dienes, 2010). Typically 70% of responses in the artificial grammar learning and similar tasks are attributable to unconscious structural knowledge, with performance levels around 65%. Unconscious structural knowledge is not something that can be conveniently ignored. Note also that striking qualitative differences were obtained when responses were separated out on a trial by trial basis – certain task conditions may on balance favour conscious or unconscious knowledge, but tasks are unlikely to be process pure (Jacoby, 1991).

5.3. Summary

The conscious-unconscious distinction that comes out most strongly as a real divide in nature is between conscious and unconscious structural knowledge rather than between conscious and unconscious judgment knowledge. Unconscious judgment knowledge corresponds to cases of unconscious structural knowledge so establishing that judgment knowledge is unconscious is useful in picking out one of the learning mechanisms; but conscious judgment knowledge (associated with intuition, familiarity and other fringe feelings) can also result from unconscious structural knowledge.

1. In Dienes, 2008, the Pedersini study was misreported as showing a difference in the time of application of conscious versus unconscious structural knowledge; in fact the zero point on the time axis for the graphs in Dienes 2008 was not defined as when the string was presented but as simply three seconds from before feedback was given (feedback was given a set time after the subject responded, not a set time from when the string was displayed). For this experiment, the time relative to the presentation of the string is unknown. Thus the time it takes for structural knowledge to apply cannot be inferred from the graph. Nonetheless, the results do show a striking difference between conscious and unconscious structural knowledge.

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Now we have a method with some evidence of its worth (and more of course needed), we can use it to explore the conscious-unconscious distinction further. We consider as examples some recent applications of the method: First to the issue of whether there are Asian-Western cross-cultural differences in unconscious processes; and second to the learning of stimuli modelled on natural language.

6. Cross cultural differences in unconscious processes

Nisbett and colleagues have been arguing for the last couple of decades that one's cultural background can profoundly affect cognitive processes (e.g. Nisbett, 2003). Specifically, Asians compared to Westerners take a more global rather than analytic perspective, being especially sensitive to context in conscious perception, memory, reasoning and social attributions, with Westerners often having the reverse tendency. For example, Masuda and Nisbett (2001) presented Japanese and Americans with underwater scenes. In a subsequent recognition test, Japanese recognized previously seen objects more accurately when they saw them in their original settings rather than in novel settings, whereas this manipulation had relatively little effect on Americans. Japanese tended to pay attention to the scene globally, whereas Americans focused more on foreground objects.

A wealth of studies have investigated cross cultural differences in conscious processing, showing consistent medium to large effects for global/analytic differences. However, the question of whether unconscious processes are affected by culture remains unanswered. Reber (1989) argued that some minimal level of attention was needed for implicit learning to occur (cf. also e.g. Jiménez, & Méndez, 1999). Thus, one might expect different attentional preferences in different cultures to lead to acquiring unconscious knowledge of different types of structures. Kiyokawa, Dienes, Tanaka, Yamada, and Crowe (submitted) tested this claim using an artificial grammar learning paradigm developed by Tanaka et al. (2008).

Tanaka et al. (2008) showed how global vs local attention could be separated in artificial grammar learning. They used "GLOCAL" strings (an example is shown in Figure 1) which are chains of compound letters (Navon, 1977). A compound letter represents one large letter (i.e., a global letter) composed of a set of small letters (i.e., local letters). A critical feature of this stimulus is that while a GLOCAL string can be read as one string at the global level (NVJTVJ in Figure 1), it can also be read as another string at the local level (BYYFLB in Figure 1). Tanaka et al. found that when

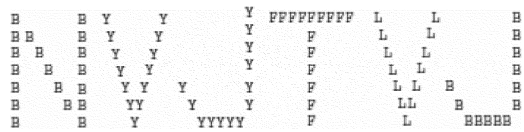

Figure 1. A GLOCAL string

people were instructed to attend at one particular level (global or local), they learned the grammar at that level, but not at the unattended level, confirming Reber's claim of a minimal amount of attention needed for implicit learning (see also Eitam et al., 2009, for a related finding).

Kiyokawa et al. asked psychology students from Chubu University in Japan and from University of Sussex in the UK to attend to GLOCAL strings embodying two different grammars at the local and global level. For the group considered here, no instructions as to which level to attend were given. In a test phase, strings were presented in normal font, i.e. not in GLOCAL format, and their knowledge of each grammar tested, accompanied by structural knowledge attributions.

For conscious structural knowledge attributions, the proportion of correct responses was much higher for the global (83%) rather than the local (53%) grammar for the Japanese participants, but there was no global advantage for the UK students (75% versus 76%). These results conceptually replicate the pre-existing literature: For conscious processing, Asian people show a greater global preference than Western people. The real contribution of the study comes from considering cross cultural differences in unconscious knowledge. For unconscious structural knowledge, the proportion of correct responses was much higher for the global (67%) rather than the local (51%) grammar for the Japanese participants, but there was no global advantage for the UK students (60% versus 61%). In sum, Japanese participants showed a striking global advantage, performing at chance on local structure, whereas the UK participants learned similarly from both global and local levels. Importantly, this effect occurred when people were apparently unaware of the contents of the structural knowledge they had induced. Thus, cultural biases can profoundly affect the contents of unconscious and not just conscious states.

7. Learning language-like structures

Our second example of the application of measuring the conscious status of structural knowledge is the learning of language-like structures. Rebuschat and Williams (2009) pointed out that "despite the widespread recognition that language acquisition constitutes a prime example of implicit learning . . . relatively little effort has been made, within linguistics or experimental psychology, to investigate natural language acquisition within the theoretical framework provided by implicit learning research". Indeed, the structures typically investigated within the implicit learning field are exemplars, chunks, conditional probabilities, or repetition patterns (see e.g. Pothos, 2007, for a review). These structures are generally relevant for learning in most any domain. But does learning within particular domains, e.g. language, come with biases or capabilities or limitations (either innate or based on experience) for learning particular structures beyond those most generic ones? Here we explore the acquisition of structures more closely resembling natural language than has been typical in the implicit learning literature.

Rebuschat and Williams (2009) presented English speaking subjects with two-clause sentences constructed from English words, but with the order of words obeying the rules of German grammar (e.g. "Last year visited Susan Melbourne because her daughter in Australia lived"). In particular, the authors were interested in whether the subjects could learn the rules of verb phrase placement, which vary according to whether the clause is main or subordinate and the first or second clause in the sentence. In the training phrase subjects assessed the semantic plausibility of the sentences. In the test phase, subjects were informed of the existence of rules and asked to classify sentences made of completely new words. The test sentences were either grammatical or violated one or other of the placement rules. After each grammaticality judgment subjects gave their structural knowledge attribution (guess, intuition, rules or memory). When people used intuition they classified significantly above baseline, indicating unconscious structural knowledge. People also classified well when they said they used rules, which appears to indicate some conscious structural knowledge. However, in free report at the end of the experiment no subject could articulate useful rules. The latter result likely reflects the insensitivity of free report we have already discussed, and the greater sensitivity of the structural knowledge attributions to picking up conscious knowledge of structure than free report allows. An alternative possibility is that the rules attributions may actually have reflected unconscious structural knowledge guiding people who consciously held only vague and uninformative rules. Be that as it may, the intuition attributions provide evidence for unconscious structural knowledge of verb placement regularities that can apply to new words. In other words, subjects had unconscious knowledge of relations that went beyond exemplars, chunks or statistics over words in themselves, and applied to verb placement within phrases.

Second language vocabulary acquisition is an area where conscious learning has been emphasized (e.g. Ellis, 1994). Guo et al. (in press) explored an aspect of vocabulary acquisition, namely semantic prosody, that plausibly involves unconscious knowledge. Semantic prosody is the contextual shading in meaning of a word, largely uncaptured by dictionary definitions. Prosodies are often positive or negative; that is, the target word is frequently used with either positive or else negative surrounding words. For example, the word "cause" may seem to have the simple meaning "to bring about", but because the word is largely used in contexts in which a negative event has been brought about (a tendency that the Oxford English Dictionary does not mention) the word has a negative semantic prosody. Chinese participants learning English were exposed to English sentences containing one of six pseudo-words, presented as real words, that substituted for a corresponding English word with known positive or negative prosody (like "cause"). In the training phase, participants read sentences providing a consistent positive or negative context for each pseudo-word. In the test phase, participants judged the acceptability of the target pseudo-words in new sentences, which provided a context that was either consistent or inconsistent with the trained prosody. After each judgment, structural knowledge attributions were given. When participants gave unconscious as well as conscious structural knowledge attributions, they accurately discriminated appropriate and inappropriate contexts for the pseudo-words. Thus, second language vocabulary acquisition may be partly conscious, especially for core meanings, but people acquire both conscious and unconscious knowledge of shadings of meaning.

Williams (2004, 2005) constructed a rule to create noun phrases in which determiners before nouns were categorized according to animacy: living things used one set of determiners and non-living things another. (In English determiners include: 'the', 'a', 'that', 'this'.) Williams asked participants to translate Italian phrases into English, phrases which followed the form-animacy regularity mentioned. On a later test using both trained and generalization items, participants responded correctly on a forced-choice test of form-meaning connections. In a post task free report, most participants claimed that they were not aware of the relevance of animacy during training, leading Williams to suggest the knowledge of the use of different determiners for animate and inanimate objects was unconscious. Chen et al. (in press) conceptually replicated the procedure with Chinese subjects, using structural knowledge attributions to provide a more sensitive test of

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the conscious status of the structural knowledge. Chen et al. used characters unknown to the participants as determiners, in sentences that were otherwise standard Chinese. As in the Williams experiments, the correct determiner varied according to the animacy (and also distance) of the modified noun phrase. In the training phase, subjects were exposed to sentences following the regularities. In the test phase, new sentences were judged for acceptability, followed by structural knowledge attributions. When structural knowledge was unconscious, people classified the right determiner according to the animacy of the modified noun phrase at about 60% correct, significantly above chance. People also classified about 60% when using conscious structural knowledge, though no subject was willing to report any regularity in post task free report.

In natural languages determiners can be sensitive to a range of features. For example, in English, the determiners 'this' versus 'that' make a near-far distinction. In Mandarin, animacy is also relevant. Thus, animacy is a linguistically relevant feature, that is, a feature that in natural languages selects different determiner forms for different nouns. Chen et al. showed that use of another feature (smaller or larger than a prototypical dog) instead of animacy did not result in learning under the same conditions. Thus, implicit learning only becomes sensitive to some of the available regularities. We propose it is those regularities with a high prior probability of being relevant within a particular domain, a proposal that needs further investigation (for other examples see Ziori & Dienes, 2008; also: Dienes, Kuhn, Guo, & Jones, in press; Rohrmeier & Cross, 2010; Rohrmeier, Rebuschat, & Cross, in press).

In sum, adults learning language structures acquire unconscious as well as conscious knowledge of a range of such structures in syntax and vocabulary.

8. Structural versus statistical learning

Some of the structures people learn in implicit learning experiments can be described as straight-forwardly statistical: n-gram statistics, conditional probabilities, or even the joint or conditional probabilities of events a fixed distance apart (X - - - Y, where the blanks could be anything; Remillard, 2008). The semantic prosody in Guo et (in press), described above, is a statistical relation between a word and the valence of its context; the form-meaning correspondence in Williams (2004, 2005) and Chen et al. (in press) is a statistical association between a form and a semantic feature.

However, not all structure is straight-forwardly statistical. The structure of having mirror symmetry is not in itself statistical (Dienes & Longuet-Higgins, 2004; Kuhn & Dienes, 2005), although learning it may involve dealing with statistics (as e.g. the model of Kuhn & Dienes, 2008, does). While Rebuschat and Williams (2009) looked at learning what look like simple verb placement rules, true sensitivity to them requires sensitivity to phrases and clauses per se, and not just to words, or statistical relations between words at fixed positions. Similarly, implicit learning of recursively embedded phrase structure (Rohrmeier, Fu, & Dienes, submitted) involves more than learning statistics over the terminal elements themselves. Bayesian approaches of course recognize the need to specify prior structures (Perfors & Navarro, this volume). Bayesian approaches provide a framework for integrating learning of structure and statistics. However, calling the overall learning phenomenon "statistical learning" may prejudge divides in nature that may not exist (statistical versus structural learning) and may divert attention away from exploring the possible conscious vs unconscious learning of other interesting structures, that are not straightforwardly regarded as statistical (e.g. the structural learning investigated by Z. P. Dienes & Jeeves, 1965; cf. Halford & Busby, 2007). Thus, it might be best simply to think about the field of research as simply the acquisition of (conscious and) unconscious knowledge of structure.

9. Conclusion

This chapter has argued that the distinction between conscious and unconscious structural knowledge is an important one for learning researchers to take into account. The chapter argues for a particular simple trial-by-trial methodology (categorical attributions for the basis of judgments, as first introduced in Dienes & Scott, 2005) and attempts to justify it philosophically and scientifically. If the method does pick out the products of different learning mechanisms, as is argued, then even researchers not interested in the conscious – unconscious distinction per se, but simply interested in characterizing the nature of learning, would benefit from employing the method.

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