Dissociating Conscious and Unconscious Learning With Objective and Subjective Measures

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Dissociating conscious and unconscious learning with objective and subjective measures

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Abstract

According to functionalist theories of consciousness, consciousness can be defined by the functions that it serves and by the way it contributes to cognition. For example, when trying to establish dissociations between conscious and unconscious knowledge, conscious representations would be identified by virtue of the fact that they allow cognitive control or successful identification or recollection assessed by verbal reports or forced-choice tasks.

Even though the functionalist approach has brought about important dissociation results concerning conscious and unconscious cognition, critics emphasize that it does not account for the qualitative properties of conscious experience. Phenomenal theories are precisely based on the notion that conscious representations are representations such that it feels like something to have these representations. Thus, one way to assess conscious knowledge is to ask people, after they have produced a forced-choice response, to identify their mental states through the use of subjective confidence ratings in which they discriminate between a complete guess and a response based on some feeling of knowing.

These two approaches are not mutually exclusive though. In this paper, we review a series of studies showing that the joint use of objective judgments about some external stimuli and about one's own subjective knowledge concerning these stimuli provides new insights into the putative dissociation between conscious and unconscious knowledge in learning.

1. Introduction

We like to think that we are always conscious of what we are doing, saying or seeing in our everyday life. In this sense, we consider all of our actions to be intentional and controlled, and view them as part of our conscious phenomenological experience. However, how could automatic behaviour, verbal slips or failures of attention, such as those involved in magic tricks, fit in this picture? These examples suggest that our experience of the world may not be 100% conscious after all. As such, we can learn and memorize information in the absence of a fully conscious experience; those phenomena have been coined 'implicit learning', 'implicit memory' and, more broadly, 'implicit cognition'.

Beyond the fascinating nature of these phenomena, an essential question concerns the extent to which one can actually make use of the knowledge acquired without intention to do so. This question is directly relevant to a vivid debate amongst researchers about the assessment of how much explicit, conscious, and controllable this knowledge can be. Here, we focus on implicit learning because the issue of identifying the best measure of conscious and unconscious influences has been —and still is— particularly debated in that field. As Zoltan Dienes recently claimed: " It is vital for learning researchers to have a means for determining the conscious or unconscious status of knowledge, suitably defined." (2012, p. 338).

Implicit learning is construed as the ability to pick up regularities in complex environments, without the intention to do so and in such a way that the resulting knowledge is difficult to express. Many paradigms have been developed to explore implicit learning (Cleeremans, Destrebecqz, & Boyer, 1998; Shanks, 2005). Here, we will focus on two of the most often used paradigms: artificial grammar learning and sequence learning. The artificial grammar learning task (AGL) developed by Reber in 1967 involves a memorization phase and a classification phase. In the first phase, participants are asked to memorize a set of letter strings generated by a finite-state grammar. In the second phase, they are told that the strings follow the rules of a grammar, and are asked to classify new strings as grammatical or not. Typically, subjects can perform this classification task better than chance would predict despite remaining unable to verbally describe the rules of the grammar. In sequence learning situations (SL), participants are asked to react to each element of sequentially structured and typically visual sequences of events in the context of a choice reaction time task. On each trial, a stimulus appears at one of several locations on a computer screen and participants are asked to press as fast and as accurately as possible on the corresponding key. Unknown to them, the sequence of successive stimuli follows a repeating pattern (Nissen and Bullemer, 1987). Reaction times decrease progressively with practice but then dramatically increase when the repeating pattern is modified in any of several ways. This suggests that participants can better prepare their responses as a result of their knowledge of the pattern. Again, this change in performance is not accompanied by the ability to produce verbalizable knowledge of the sequence.

This dissociation between task performance (i.e., classification accuracy in AGL or reaction times in SL) and verbal reports has led many authors to describe learning as implicit or unconscious in such situations, because participants appear to be sensitive to and can apply knowledge that they nonetheless remain unable to describe and had no intention to learn in the first place. This approach corresponds to functionalist theories of consciousness, where consciousness can be defined by the functions that it serves (verbal access, recollection and control) and by the way it contributes to cognition.

The operational definition of consciousness differs in phenomenal theories, with a focus on the *qualitative* properties of conscious experience. In this case, what it feels like to possess certain knowledge is under scrutiny: Conscious learning is associated with the ability to produce a subjective judgment about what is learned. Here we argue that finding a proper measure of awareness requires a satisfactory operational definition of the concept (but see Rünger & Frensch, 2010, who advocate for a conceptual definition of consciousness instead). In the following, we present both perspectives and argue that a combination thereof is necessary in order to reach an accurate description of what is learned regarding its conscious or unconscious nature.

2. Functionalist approach

Destrebecqz & Peigneux (2005) developed a useful taxonomy of the different measures of conscious knowledge. That classification is based on the functions that consciousness serves. Consciousness indeed allows 1) verbal access to the acquired knowledge, 2) recollection of the acquired knowledge and 3) control over the expression of the acquired knowledge. Accordingly, conscious knowledge can be assessed through 1) verbal reports and questionnaires, 2) forced-choice classification, recognition and generation tasks, and 3) the comparison between direct vs. indirect or inclusion and exclusion tasks. In the next sections, we survey the experimental procedures tapping those three functions and compare their ability to provide accurate measures of consciousness.

2.1. Verbal access

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 (Reber, 1967; Nissen & Bullemer, 1987; Curran, 1997; Frensch, Lin, & Buchner, 1998). Their use is nevertheless controversial: on the one hand, verbal reports constitute an essential way of addressing and measuring consciousness

(Overgaard, 2001; Rünger & Frensch, 2010), but on the other hand, 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 (see namely the information and sensitivity criteria in Shanks & St John, 1994). There is no doubt, however, that one is conscious of some information if he/she can describe it verbally: this is the case for participants who are able to indicate the serial order of response locations in a SL experiment, or the grammaticality rules in an AGL experiment. But poor performance on questionnaires or verbal reports does not necessarily imply that participants are unaware of some information. Tests of verbal awareness are indeed subject to several biases (see Shanks, 2005). For instance, since most of verbal reports are collected at the end of a given task, participants may forget or inaccurately recall the relevant features of the experimental situation. They may also fail to report conscious knowledge held with low confidence. Using verbal reports or questionnaires as the only measure of conscious knowledge might thus overestimate unconscious learning. As a consequence, forced-choice tasks have been developed as an alternative, sometimes complementary way to assess conscious knowledge at the end of the learning phase.

2.2. Recollection

According to the second operational definition of consciousness, participants are deemed to have gained conscious access to the sequential regularities or the grammatical rules of the material if they are able to make use of their knowledge in a subsequent test phase. Under the assumption that consciousness allows recollection of the acquired knowledge, these tests have generally taken the form of a grammaticality classification or stem completion task in AGL, and of a generation or recognition task in SL. Because those tasks implement retrieval conditions more similar to the learning task than verbal reports, they are more likely to meet the information and sensitivity criteria (Shanks & St John, 1994). They are assumed to detect conscious knowledge left undetected by verbal reports or questionnaires. Above-chance performance in those direct tasks has therefore been opposed to the failure to report the underlying grammatical rules or the sequential regularity (see Cleeremans, Destrebecqz, & Boyer, 1998; Frensch & Rünger, 2003; Shanks, 2010 for reviews). For instance, in SL, Perruchet and Amorim (1992) reported reliable associations between motor improvement in the learning task and performance in a subsequent recognition task. This was taken as evidence 1) that participants are able to express a great deal of the knowledge they acquired in the learning phase and 2) that this knowledge is not as unconscious as previously thought, if unconscious at all.

But above-chance performance in those forced-choice tasks is not necessarily driven by conscious knowledge only (Jiménez, Méndez, & Cleeremans, 1996). Indeed, it has been shown in SL 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 & 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 (Perruchet & Amorim, 1992). Performance in the recognition and generation tasks, rather than depending exclusively on conscious knowledge, is thus likely to depend on both implicit and explicit influences.

The fluency hypothesis has also been proposed in AGL, where the exposure to grammatical strings is assumed to improve processing fluency (Pothos, 2007). This generates a feeling of familiarity, leading itself to endorse the strings as grammatical in the classification task (but not in a recognition task, see Kinder, Shanks, Cock, & Tunney, 2003), even if the knowledge on which this (conscious) feeling of familiarity is based is not consciously recollected. Recent methodological developments in AGL also indicate that above-chance performance in a forced-choice classification task does not necessarily reflect conscious knowledge of the grammatical rules. Forkstam, Elwér, Ingvar, and Petersson (2008) compared performance in a typical grammaticality classification task and in a preference classification task, based on the mere exposure effect (Zajonc, 2001). The grammaticality classification task requires informing participants about the existence of a set of grammatical rules after exposure to the learning material. In a preference classification task, by contrast, there is no need to refer to the previous learning phase or to indicate the existence of a set of rules: participants have merely to tell their preference for new strings based on a gut feeling. It is thus highly unlikely that participants would prefer grammatical strings more than non-grammatical ones based on conscious knowledge. Above-chance performance is nevertheless observed in the preference classification task, suggesting that participants do indeed prefer new grammatical strings. Moreover, Forsktam and colleagues (2008) showed that preference classification and grammaticality classification are behaviourally equivalent. Even if these results do not demonstrate unconscious learning, they show that explicit reference to the rules structuring the material does not improve performance in a direct measure of learning. They therefore suggest that direct measures are not necessarily based on conscious knowledge.

To sum up, the assessment of conscious knowledge with forced-choice tasks is controversial, to say the least. On the one hand, those tasks have been initially developed in order to maximize the detection of conscious knowledge left undetected by verbal reports. On the other hand, forced-choice tasks are not immune from contamination by unconscious knowledge. Relevant discussion on the ability of those tasks to tap conscious and/or unconscious knowledge can be found in Shanks (2005, 2010) and Perruchet (2008).

2.3. Control

The third operational definition of consciousness in Destrebecqz and Peigneux's (2005) taxonomy refers to the idea that knowledge can be considered conscious if its expression can be intentionally controlled, as in the Process Dissociation Procedure (PDP), initially developed by Jacoby (1991) in the field of implicit memory research. 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 these influences either both contribute to performance —the *inclusion* task— or are set in opposition —the *exclusion* task. In other words, in the inclusion task, both types of knowledge can lead to a correct response whereas in the exclusion task, only conscious knowledge of the regularities can lead to the correct rejection of certain stimuli. The inclusion and exclusion tasks only differ with respect to their instructions.

Destrebecqz and Cleeremans (2001) applied this procedure to SL in a forced-choice generation task: 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. Under exclusion instructions however, 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 Process Dissociation Procedure, 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 by which exclusion performance exceeds baseline.

Several researchers later used the forced-choice generation task under inclusion and exclusion instructions (Wilkinson & Shanks, 2004; Shanks, Rowland, & Ranger, 2005; Dennis, Howard, & Howard, 2006; Ferdinand, Mecklinger, & Kray, 2008; Fu, Fu, & Dienes, 2008; Stefaniak, Willems, Adam, & Meulemans, 2008; Gheysen, Gevers, De Schutter, Van Waelvelde, & Fias, 2009; Gheysen, Van Opstal, Roggeman, Van Waelvelde, & Fias, 2010; Fu, Q., Dienes, Z., & Fu, X., 2010; Haider, Eichler, & Lange, 2011, Jiménez, Méndez, Pasquali, Abrahamse, & Verwey, 2011; Abrahamse, van der Lubbe, Verwey, Szumska, & Jaskowski, 2012; Goschke & Bolte, 2012; Schuck, Frensch, Schjeide, Schröder, Bertam, & Li, 2013; Schulz, Stevens, Keller, & Tillmann, 2013; Fu, Q., Bin, G., Dienes, Z., Fu, X., & Gao, X., 2013). The PDP has also been applied in a forced-choice recognition task, where only a subset of sequences had to be considered as "old" or "well-formed" (Buchner, Steffens, Erdfelder, & Rothkegel, 1997; Mong, McCabe, & Clegg, 2012).

Finally, Higham, Vokey, & Pritchard (2000) used the PDP in AGL. Participants were exposed to two different sets of letter strings, generated from two different grammars: Grammar A and Grammar B. Then they had to classify novel letter strings as grammatical or not under inclusion and exclusion instructions. Inclusion instructions consisted in accepting both kinds of grammatical novel sequences while exclusion instructions required to exclude ungrammatical strings of letters as well as novel A or B sequences[1]. The general conclusion

1 It is to note that Dienes, Altmann, Kwan, & Goode (1995) also incidentally exposed participants to two separate sets of rules in the study phase and then asked them to endorse strings from only one of the grammars (i.e., the 'consistent grammar') in the test phase. Estimates of strategic vs. obligatory knowledge were derived from the endorsement rates of consistent, inconsistent and ungrammatical strings. This procedure is very similar to the exclusion instructions in the PDP, but does not allow for a within-subject comparison between inclusion and exclusion performance (see also Wan, Dienes, & Fu, 2008).

emerging from many of the PDP studies is that performance in forced-choice generation, recognition or classification tasks stems from both conscious and unconscious knowledge (but see Wilkinson & Shanks, 2004; Shanks et al., 2005 for notable disagreement).

Despite its extended application in implicit learning research, the PDP has also raised many controversial issues, regarding the hypothetical relationship between both conscious and unconscious influences (see Richardson-Klavehn, Gardiner, & Java, 1996), the complexity of the instructions (Graf & Komatsu, 1994), or the difficulty in interpreting results associated with those parts of the generated sequence that are not "correct" in the sense that they do not correspond to the training material but respect the exclusion instructions (Stefaniak et al., 2008).

Moreover, the postulated relationship between consciousness and intentional control in the PDP has also been the topic of very contrasted claims. According to Rünger & Frensch (2010), a too strict functionalist definition of consciousness, such as the one used in PDP paradigms, does not provide a satisfactory and exhaustive measure of conscious knowledge. They claimed that the main function of consciousness is to allow global availability to various cognitive processes and that, in this view, verbal reports remain the best way to assess conscious knowledge. At the other end of the spectrum, Mong et al. (2012) argue that instead of trying to measure the influence of conscious and unconscious knowledge, research on implicit learning should only focus on the difference between automatic and controlled processes. These two radical attitudes are not however without causing arduous conceptual and methodological issues. First, defining consciousness as the ability to exert intentional control over the acquired knowledge fails, however, to capture one of its essential aspects, i.e., the qualitative, subjective or first-order properties of conscious experience (see Wierzchon, Asanowicz, Paulewicz, & Cleeremans, 2012). Second, as consciousness differs from reportability, self-reports should not be used as the only measurement tool but in conjunction with other, more sensitive, subjective measures.

Phenomenal theories may address these two shortcomings of functional theories as they are precisely based on the notion that conscious representations are representations such that it feels like something to have these representations. Thus, one way to assess conscious knowledge is to ask people, after they have produced a forced-choice response, to identify their mental states through the use of first-person, subjective measures.

3. Phenomenal approach

The phenomenal approach encompasses the coupling of objective and subjective measures of consciousness. As seen in the preceding sections, the third-person, objective measures require participants to indicate whether they are able to discriminate between features of the world (''worldy discrimination''), whereas first-person, subjective measures require participants to discriminate between their own mental states (''mental state discrimination'') (Fu, Fu, & Dienes, 2008).

3.1. Confidence ratings

Confidence ratings are probably the most typical subjective measure. After participants made a forced-choice response, they are asked to indicate whether they are confident in their decision, by means of binary or graded confidence scales (Tunney & Shanks, 2003). This coupling of objective and subjective measures combines the use of a subjective and an objective threshold in order to identify responses based on conscious or unconscious knowledge (Dienes & Berry, 1997). A participant performing above chance in a forced-choice task (i.e., performance is above the objective threshold) but claiming to guess the correct response (i.e., confidence is below the subjective threshold) would be influenced by implicit knowledge as she is using some knowledge about the material that she does not know she has.

In other words, she is lacking a higher-order representation of her representation of the regularity. This is unconscious knowledge by the *guessing criterion* (Cheesman & Merikle, 1994; Dienes, Altmann, Kwam, & Goode, 1995). A second criterion for unconscious knowledge, the *zero- correlation criterion*, is met when confidence levels and performance rates are uncorrelated, when participants do not perform worse when they have the subjective feeling to guess than when they have the notion that they recollect the training material. Conversely, it is assumed that high correlation between confidence ratings and accurate performance indicates participants' awareness of knowing (Chan, 1992; Dienes et al., 1995).

This procedure can 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. And several studies have indeed applied these ideas in AGL and SL (see Dienes & Seth, 2010). Confidence ratings have been criticized, however, on the grounds that they may be counter-intuitive to participants, or that they may be individually biased, as it is the case for verbal reports. As a solution to this problem, Tunney & Shanks (2003) used binary confidence ratings in AGL, and categorized them in terms of signal detection theory. This procedure ensures unbiased measure of confidence. Recently, the conjoint use of confidence ratings and other scales, such as the feeling of warmth (FOW) scale or the rule awareness scale (RAS) has also been proposed as a way to enable a finer assessment of subjective states of awareness in AGL (Wierzchon et al., 2012).

Regardless of these improvements, other concerns have also been raised. Rünger & Frensch (2010) cast doubt concerning the ability of confidence ratings to provide an assessment of the actual conscious knowledge that was used when performing discrimination the confidence judgment is about. For instance, in line with the fluency hypothesis, participants may be rather confident that a given letter string is grammatical based on easier and faster processing. In other words, confidence ratings may express participants' subjective experience of accessibility in a way that is not necessarily accompanied by full conscious access to the knowledge itself, just as one can be 100% confident that a given sentence is not grammatical, without recollecting the exact rules upon which his/her decision was made.

Metacognitive or higher-order thought theories go one step further in the phenomenal approach: "To establish that knowledge is conscious one must establish that the subject is in a metacognitive state of knowing about knowing" (Dienes, 2012, p.338). In other words, the relevant requirement for a representation to be a conscious representation is that it should be related to a higher-order representation of that very representation such that one has to be conscious to have that representation. This corresponds to what Dienes and Scott (2005) coined conscious structural knowledge.

3.2. Structural and judgment knowledge

In AGL and SL studies, participants acquire knowledge of the structure of training items during the training phase: this is called structural knowledge. The debate regarding the exact nature of this acquired knowledge is beyond the scope of the present paper, so let's just say that participants can learn rules, whole sequences, fragments of items, or statistical regularities (see Perruchet, 2008). In the subsequent test phase this structural knowledge is applied to the specific test items (letter strings, sequence fragments) in order to determine whether they do or do not share that structure: this is called judgment knowledge. Subjective measures based on confidence ratings, like the guessing and zero correlation criteria, assess the conscious status of judgment knowledge only.

For the sake of illustration, let's imagine four participants in an AGL study, randomly assigned to two different training conditions: Participants A, B and C were incidentally exposed to the training strings, whereas participant D knew in advance that the strings were generated from rules and intentionally tried to identify those rules. In the test phase, participant A was not able to discriminate between grammatical and ungrammatical test strings and claimed to guess on every trial. Participant B performed above chance in the grammaticality classification task (i.e., accuracy was above the objective threshold) but was not more confident in his correct than in his incorrect decisions (i.e., accuracy and confidence did not correlate). Participant C also classified test strings better than chance would predict and was furthermore systematically more confident in his correct responses than when he made a wrong classification so that his performance was above the subjective threshold. Based on the coupling of accuracy and confidence measures, one can conclude that 1) Participant A just did not learn the grammar; 2) Participant B has acquired unconscious judgement knowledge, because he is able to discriminate between features of the world without phenomenally experiencing that ability; 3) Participant C has acquired conscious judgment knowledge, in the sense that he can perform correct discriminative judgments and knows when he is using his knowledge adequately. However, this does not necessarily mean that he is aware of the structural knowledge that enabled these judgments. His decisions could have been based on a conscious sense of fluency or familiarity, and not on any specific structural knowledge such as "An X can start a string" or " letters cannot repeat themselves". Finally 4) Participant D also expressed conscious judgment knowledge according to the guessing and zero correlation criteria. In addition, as he knew there were rules in the material and searched for them, there is a good chance that he learned the structure of the strings as reflecting underlying rules, and therefore acquired conscious structural knowledge.

The conscious status of structural knowledge can be measured through a method devised by Dienes and Scott (2005), where participants have to discriminate their mental state on a trial-by-trial basis. Dienes (2012) developed the method as follows: After each classification judgment, participants indicate what was the basis of their judgment according to a set of attribution categories: random (the judgment was based on a pure guess); intuition (it had some basis but the participant had no idea what it was); familiarity (the decision was based on a feeling of familiarity but the participant 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 finally, rules (the basis was a rule or rules that the participant could state if asked).

If we go back to our fictitious participants, we can consider that participant A did not learn, participant B made random attributions, participant C used intuition and familiarity attributions, and participant D referred to recollection and rules. In other words, participant A had no knowledge whatsoever. Both judgment and structural knowledge were unconscious in the case of participant B. Judgment knowledge was conscious but structural knowledge was unconscious in the case of participant C. Finally, participant D had conscious judgment *and* conscious structural knowledge.

In sum, combining objective judgments about some external stimuli and about one's own metacognitive knowledge concerning these stimuli provides new insights into the putative dissociation between conscious and unconscious knowledge in learning. Fu, Dienes, and Fu (2010) recently added those metacognitive attributions to the PDP method in SL, to assess the conscious status of structural knowledge. They reasoned that the PDP only measures the conscious status of judgment knowledge, because participants only need to know which location is legal in order to perform the generation task under inclusion and exclusion instructions. Thus knowing why a given location is legal is not necessary to respond. By contrast, the attribution test of Dienes and Scott (2005) requires that participants attribute the basis of their classification decisions to either guess, intuition, rules, or memory. In their second experiment, Fu and colleagues (2010) demonstrated that the conscious judgment knowledge expressed in the difference between inclusion and exclusion scores could be based on rules and memory on the one hand, but also on intuition on the other hand. In other words, participants were sometimes able to exert control over the sequential knowledge when claiming they did not know what the basis of their judgment was. As the volitional control of knowledge is the trademark of consciousness according to the PDP, this suggests that the PDP only is not suited to measure the conscious status of structural knowledge. Metacognitive attributions are needed.

4. Conclusion

In this short article, we have tried to make a synthetic presentation of the conceptual and methodological challenges related to the dissociation and measurement of conscious and unconscious learning. We proposed that the difficulty of this endeavour is related to the different operational definitions of consciousness that follow from functionalist and phenomenal theories of consciousness. Functionalist theories focus on what consciousness does while phenomenal theories are concerned with what it feels like. For decades, implicit learning research has been centered on identifying the respective shortcomings of the various methods used to measure conscious and unconscious knowledge. More recently, studies have instead started to adopt integrative approaches in which third- and first-person data are taken in conjunction in order to reach a better assessment of the extent to which behaviour may reflect the influence of unconscious structural knowledge. Similar strategies are also used in the domain of subliminal perception where sensitive scales based on intuition are used to measure awareness of briefly flashed visual stimuli (Ramsøy & Overgaard, 2004).

5. References

Abrahamse, E. L., van der Lubbe, R. H. J., Verwey, W. B., Szumska, I., & Jaskowski, P. (2012). Redundant sensory information does not enhance sequence learning in the serial reaction time task, Advances in Cognitive Psychology, 8(2), 109-120, doi 10.2478/v10053-008-0108-y

Buchner, A., Steffens, M. C., Erdfelder, E., & Rothkegel, R. (1997). A Multinomial Model to Assess Fluency and Recollection in a Sequence Learning Task, The Quarterly Journal of Experimental Psychology Section A, 50(3), 631-663, doi 10.1080/713755723

Chan, C. (1992). Implicit cognitive processes: Theoretical issues and applications in computer systems design (Unpublished doctoral dissertation). University of Oxford, Oxford, England

Cheesman, J., & Merikle, P. M. (1984). Priming with and without awareness. Perception & Psychophysics, 36, 387–395, doi 10.3758/ BF03202793

Cleeremans, A., Destrebecqz, A., & Boyer, M. (1998). Implicit learning: News from the front. Trends in Cognitive Sciences, 2(10), 406-416, doi 10.1016/S1364-6613(98)01232-7

Curran, T. (1997). Effects of aging on implicit sequence learning: Accounting for sequence structure and explicit knowledge. Psychological Research, 60, 24-41, doi 10.1007/BF00419678

Dennis, N. A., Howard, J. H., & Howard, D. V. (2006). Implicit sequence learning without motor sequencing in young and old adults. Experimental Brain Research, 175, 153-164, doi 10.1007/s00221-006-0534-3

Destrebecqz, A., & Cleeremans, A. (2001). Can sequence learning be implicit? New evidence with the process dissociation procedure. Psychonomic Bulletin & Review, 8(2), 343–350, doi 10.3758/BF03196171

Destrebecqz, A., & Peigneux, P. (2005). Methods for studying unconscious learning. Progress in Brain Research, 150, 69-80, doi 10.1016/S0079-6123(05)50006-2

Dienes, Z. (2012). Conscious versus unconscious learning of structure. In P. Rebuschat & J. Williams (Eds.), Statistical Learning and Language Acquisition. Walter de Gruyter Publishers (pp. 337 - 364)

Dienes, Z., Altmann, G., Kwan, L., & Goode, A. (1995). Unconscious knowledge of artificial grammars is applied strategically. Journal of Experimental Psychology: Learning, Memory and Cognition, 21(5), 1322–1338, doi 10.1037/0278-7393.21.5.1322

Dienes, Z., & Berry, D. (1997). Implicit learning: Below the subjective threshold. Psychonomic Bulletin & Review, 4, 3–23, doi10.3758/ BF03210769

Dienes, Z., & Seth, A. (2010). Gambling on the unconscious: A comparison of wagering and confidence ratings as measures of awareness in an artificial grammar task. Consciousness and Cognition, 19(2), 674–681, doi 10.1016/j.concog.2009.09.009

Dienes, Z., & Scott, R. (2005). Measuring unconscious knowledge: Distinguishing structural knowledge and judgment knowledge. Psychological Research, 69(5-6), 338–351, doi 10.1007/s00426-004-0208-3

Ferdinand, N. K., Mecklinger, A., & Kray, J. (2008). Error and deviance processing in implicit and explicit sequence learning. Journal of Cognitive Neuroscience, 20(4), 629-642, doi 10.1162/jocn.2008.20046

Forkstam, C., Elver, A., Ingvar, M., & Petersson, K. M. (2008). Instruction effects in implicit artificial grammar learning: A preference for grammaticality. Brain Research, 1221, 80-92, doi 10.1016/j.brainres.2008.05.005

Frensch, P. A., Lin, J., & Buchner, A. (1998). Learning versus behavioural expression of the learned: The effects of a secondary tone-counting task on implicit learning in the serial reaction time task. Psychological Research, 61(2), 83-98, doi 10.1007/s004260050015

Frensch, P. A., & Rünger, D. (2003). Implicit learning. Current Directions in Psychological

Science, 12(1), 13-18, doi 10.1111/1467-8721.01213

Fu, Q., Bin, G., Dienes, Z., Fu, X., & Gao, X. (2013). Learning without consciously knowing: Evidence from event-related potentials in sequence learning. Consciousness and Cognition, 22(1), 22-34, doi 10.1016/j.concog.2012.10.008

Fu, Q., Dienes, Z., & Fu, X. (2010). Can unconscious knowledge allow control in sequence learning? Consciousness and Cognition, 19, 462-474, doi 10.1016/j.concog.2009.10.001

Fu, Q., Fu, X. & Dienes, A. (2008). Implicit sequence learning and conscious awareness. Consciousness and Cognition, 17(1), 185-202, doi 10.1016/j.concog.2007.01.007

Gaillard, V., Vandenberghe, M., Destrebecqz, A., & Cleeremans, A. (2006). First- and third-person approaches in implicit learning research. Consciousness and Cognition, 15(4), 709–722, doi 10.1016/j.concog.2006.08.001

Gheysen, F., Gevers, W., De Schutter, E., Van Waelvelde, H., & Fias, W. (2009). Disentangling perceptual from motor implicit sequence learning with a serial color-matching task. Experimental Brain Research, 197(2), 163-174, doi 10.1007/s00221-009-1902-6

Gheysen, F., Van Opstal, F., Roggeman, C., Van Waelvelde, H., & Fias, W. (2010). Hippocampal contribution to early and later stages of implicit motor sequence learning. Experimental Brain Research, 202 (4), 795-807, doi 10.1007/s00221-010-2186-6

Goschke, T. & Bolte, A. (2012). On the modularity of implicit sequence learning: Independent acquisition of spatial, symbolic, and manual sequences. Cognitive Psychology, 65(2), 284-320, doi 10.1016/j.cogpsych.2012.04.002

Graf, P. & Komatsu, S. (1994). Process Dissociation Procedure: Handle with caution! European Journal of Cognitive Psychology, 6(2), 113-129, doi 10.1080/09541449408520139

Haider, H., Eichler, A., & Lange, T. (2011). An old problem: How can we distinguish between conscious and unconscious knowledge acquired in an implicit learning task? Consciousness and Cognition, 20(3), 658-672, doi 10.1016/j.concog.2010.10.021

Higham, P. A., Vokey, J. R., & Pritchard, J. L. (2000). Beyond dissociation logic: Evidence for controlled and automatic influences in artificial grammar learning. Journal of Experimental Psychology: General, 129(4), 457–470, doi 10.1037/0096-3445.129.4.457

Jiménez, L., Méndez, C., & Cleeremans, A. (1996) Comparing direct and indirect measures of sequence learning. Journal of Experimental Psychology: Learning, Memory, and Cognition, 22(4), 948-969, doi 10.1037/0278-7393.22.4.948

Jiménez, L., Méndez, A., Pasquali, A., Abrahamse, E., & Verwey, W. (2011). Chunking by colors: Assessing discrete learning in a continuous serial reaction-time task. Acta Psychologica, 1937(3), 318-329, doi 10.1016/j.actpsy.2011.03.013

Kinder, A., Shanks, D. R., Cock, J., & Tunney, R. J. (2003). Recollection, fluency, and the explicit/implicit distinction in artificial grammar learning. Journal of Experimental Psychology: General, 132(4), 551–565, doi 10.1037/0096-3445.132.4.551

Mong, H. M., McCabe, D. P., & Clegg, B. A. (2012). Evidence of automatic processing in sequence learning using process-dissociation. Advances in Cognitive Psychology, 8(2), 98-108, doi 10.2478/v10053-008-0107-z

Nissen, M. J. and Bullemer, P. (1987) Attentional requirement of learning: Evidence from performance measures. Cognitive Psychology, 19(1) 1-32, doi 10.1016/0010-0285(87)90002-8

Overgaard, M. (2001). The place for phenomenology in experiments on consciousness. Psycoloquy, 12(9), 1–13

Perruchet, P. (2008). Implicit learning. In J. Byrne (Ed.). Cognitive psychology of memory. Vol.2 of Learning and memory: A comprehensive reference, Oxford : Elsevier, pp. 597-621

Perruchet, P., & Amorim, M. A. (1992). Conscious knowledge and changes in performance in sequence learning: Evidence against dissociation. Journal of Experimental Psychology: Learning, Memory, and Cognition, 18(4), 785-800, doi 10.1037/0278-7393.18.4.785

Pothos, E. M. (2007). Theories of artificial grammar learning. Psychological Bulletin, 133(2), 227–244, doi 10.1037/0033-2909.133.2.227

Ramsøy T. Z., & Overgaard M. (2004). Introspection and subliminal perception, Phenomenology and the Cognitive Science, 3(1), 1–23, doi 10.1023/B:PHEN.0000041900.30172.e8

Reber, A. S. (1967). Implicit learning of artificial grammars. Journal of Verbal Learning and Verbal Behavior, 6(6), 855–863, doi 10.1016/S0022-5371(67)80149-X

Reber, A. S. (1989). Implicit learning and tacit knowledge. Journal of Experimental Psychology: General, 118(3), 219–235, doi 10.1037/0096-3445.118.3.219

Richardson-Klavehn, A., Gardiner, J. M. and Java, R. I. (1996) Memory: Task dissociations, process dissociations, and dissociation of consciousness. In G. Underwood (Ed.) Implicit cognition, Oxford: Oxford University Press, pp. 85-158

Rünger, D. & Frensch, P. A. (2010). Defining consciousness in the context of incidental sequence learning: theoretical considerations and empirical implications. Psychological Research, 74(2), 121-137, doi 10.1007/s00426-008-0225-8

Schuck, N. W., Frensch, P. A., Schjeide, B. M., Schröder, J., Bertam, L., & Li, S. C. (2013). Effects of aging and dopamine genotypes on the emergence of explicit memory during sequence learning. Neuropsychologia, 51(13), 2757-2769, doi 10.1016/j.neuropsychologia.2013.09.009

Schulz, B. G., Stevens, C. J., Keller, P. E., & Tillmann, B. (2013). The implicit learning of metrical and nonmetrical temporal patterns. Quarterly Journal of Experimental Psychology, 66(2), 360-380, doi 10.1080/17470218.2012.712146

Shanks, D. R. (2005). Implicit learning. In K. Lamberts & R. Goldstone (Eds.). Handbook of Cognition. Thousand Oaks, CA: Sage Publications, pp. 202-220

Shanks, D. R. (2010). Learning: From Association to Cognition. Annual Review of Psychology, 61, 273-301, doi 10.1146/annurev.psych.093008.100519

Shanks, D. R., & Johnstone, T. (1998). Implicit knowledge in sequential learning tasks. In M. A. Stadler & P. A. Frensch (Eds.), Handbook of implicit learning. Thousand Oaks, CA: Sage Publications, pp. 533–572

Shanks, D. R., Rowland, L. A., & Ranger, M. S. (2005). Attentional load and implicit sequence learning. Psychological Research, 69(5–6), 369–382, doi 10.1007/s00426-004-0211-8

Shanks, D. R., & St. John, M. F. (1994). Characteristics of dissociable human learning systems. Behavioral and Brain Sciences, 17(3), 367–395, doi 10.1017/S0140525X00035287

Stefaniak, N., Willems, S., Adam, S., & Meulemans, T. (2008). What is the impact of the explicit knowledge of sequence regularities on both deterministic and probabilistic serial reaction time task performance? Memory and Cognition, 36 (7), 1283-1298, doi 10.3758/MC.36.7.1283

Tunney, R. J., & Shanks, D. R. (2003). Subjective measures of awareness and implicit cognition. Memory and Cognition, 31(7), 1060-1071, doi 10.3758/BF03196127

Wilkinson, L., & Shanks, D. R. (2004). Intentional control and implicit sequence learning. Journal of Experimental Psychology: Learning, Memory, and Cognition, 30(2), 354-369, doi 10.1037/0278-7393.30.2.354

Wan, L., Dienes, Z., & Fu, X. (2008). Intentional control based on familiarity in artificial grmmar learning. Consciousness and Cognition, 17, 1209-1218, doi 10.1016/j.concog.2008.06.007

Wierzchoń, M., Asanowicz, D., Paulewicz, B., & Cleeremans, A. (2012). Subjective measures of consciousness in artificial grammar learning task. Consciousness and Cognition, 21(3), 1141-1153, doi 10.1037/0278-7393.30.2.354

Zajonc, R. B. (2001). Mere exposure: A gateway to the subliminal. Current Directions in Psychological Science, 10(6), 224-228, doi 10.1111/1467-8721.00154

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