

Can unconscious structural knowledge be strategically controlled?

Elisabeth Norman ¹, Ryan B. Scott ², Mark C. Price ¹ Emma Jones ¹, & Zoltan Dienes ²

¹ Faculty of Psychology, University of Bergen, Norway

² University of Sussex, UK

Word count (including front page, abstract, references, and tables): 6443

Running head: Strategic control

Correspondence should be addressed to:

Elisabeth Norman, Psychology Faculty, University of Bergen, Christies gate 12, 5020 Bergen, Norway.

E-mail: Elisabeth.Norman@psysp.uib.no.

Telephone: + 47 55 58 98 84 / + 47 48 05 89 25

Abstract

The ability to apply strategic control is commonly used a criterion for distinguishing between knowledge which is consciously available and knowledge which is not. For instance, methods based on the Process Dissociation Procedure (Jacoby, 1991) – in which performance is compared under conditions where participants attempt to apply versus withhold knowledge – are frequently used as a criterion for determining the extent to which learning is implicit or explicit. In this chapter we first present a brief overview of existing methods that have been developed for measuring strategic control in the serial reaction time (SRT; Nissen & Bullemer, 1987) and artificial grammar learning (AGL; Reber, 1967) tasks. Even though the described methods are traditionally used to determine the conscious status of acquired rule knowledge, it has also been shown that strategic control can occur in the absence of detailed conscious awareness of the learned regularities (Fu, Dienes & Fu 2010; Norman, Price, Duff, & Mentzoni, 2007; Norman, Price, & Jones, 2011; Wan, Dienes, & Fu, 2008). This challenges the assumption that strategic control requires conscious awareness (Baars, 1988; Jacoby, 1991). We present the results from an experiment that specifically addresses whether knowledge of learned grammars can be applied in a strategically controlled manner even when structural knowledge is not conscious. The procedure combines 2 different measures of consciousness of structural knowledge of grammar rules. These are the trial-by-trial evaluation of decision strategy (Dienes & Scott, 2005) and verbal report of the nature of the grammars in a situation where the grammar rules can logically be related to any of 3 stimulus dimensions (Norman et al., 2011). The results indicate that strategic control may occur even when participants express global unawareness of the nature of the rule that governs letter strings, when this is measured by self-report after the experiment.

Introduction

Strategic control refers to the ability to apply knowledge flexibly in an intentional manner according to current situational demands. If knowledge is under strategic control, this has traditionally been taken as evidence that the knowledge in question is consciously available. Examples include Jacoby (1991), who views strategic control as a criterion of consciousness, and Baars' (1988) Global Workspace Model, according to which conscious information is both controllable and available to higher order thought. However, there are also theories that do not regard strategic control as indicative of consciousness. Higher Order Thought theories do not make claims about the relationship between control and consciousness (Lau & Rosenthal, 2011; Rosenthal, 2005), and the "cold control theory" of hypnosis regards unconscious executive control as characteristic of hypnosis (Dienes & Perner, 2007). In addition, there is now a relatively large body of empirical evidence supporting the hypothesis that strategic control may occur for cognitive content that it is itself not available to consciousness. For example, Lau and Passingham (2007) found that unconsciously perceived stimuli interfered with tasks traditionally thought to require conscious control. Similarly, several studies have reported findings indicating that the go-no go network can be activated unconsciously (Hepler & Albarracin, 2013; Van Gaal, Ridderinkhof, Scholte, & Lamme, 2010), and a study by Schmidt, Crump, Cheesman, and Besner (2007) showed that participants were able to strategically control the application of learned contingencies between colour-unrelated words and colours in a contingency learning paradigm. The focus of the current chapter is on whether the application of unconscious knowledge, acquired through implicit learning, may also be strategically controlled.

Procedures for measuring strategic control in implicit learning

A number of experimental procedures have been developed for measuring strategic control in implicit learning, both within the serial reaction time task (SRT; Nissen & Bullemer, 1987) and within artificial grammar learning (AGL; Reber, 1967). Most of these are based on the logic of Jacoby's (1991) Process Dissociation Procedure, which compares performance under conditions where a person "tries to" versus "tries not to" engage in some act, and where a comparison of performance under the two conditions is seen as indicating the relative influence of conscious and unconscious knowledge.

We here give a brief overview of the most important methods for assessing strategic control in SRT and AGL learning (see Norman, 2015, for a more complete overview).

In the *serial reaction time (SRT) task*, participants are presented with a visual target that moves between positions on a computer screen according to a complex, pre-defined sequence. The instruction is to make fast key-press responses to indicate the position of the moving target, and reaction time differences between target movements that either follow or violate this sequence are taken to indicate learning. In this paradigm, strategic control refers to participants' ability to control their application of sequence knowledge according to task instructions. The most common measurement of this ability is the *generation exclusion task*, in which participants are instructed to generate a sequence that is different from the sequence on which they have been trained (Destrebecqz & Cleeremans, 2001; Goschke, 1998). Strategic control can be assessed by comparing performance under these instructions and under conditions when participants try to generate the trained sequence (i.e., *inclusion* instructions). Two varieties of the inclusion/exclusion generation task are *free generation*, in which the participants freely generate an n -element sequence (e.g., Destrebecqz & Cleeremans, 2001), and *cued generation*, where each trial involves generating a continuation response to a short sequence of, e.g., 3-5 sequence elements. An alternative procedure is the *generation rotation task* (Norman, Price, Duff, & Mentzoni, 2007). This is designed to avoid the possibility that successful exclusion performance could be influenced by a global inhibition of the influence of acquired knowledge, rather than by a moment-to-moment monitoring of this knowledge. During training and generation, stimuli are presented in a square layout. In a cued generation task, participants are instructed to predict the next target position. However, the stimulus-response mapping varies between individual trials. More specifically, participants are told to rotate their response, clockwise or anticlockwise, in accordance with a randomly varying cue (-1, +1, -2) indicated on screen. Yet another procedure is the *inclusion/exclusion recognition task* (Mong, McCabe, & Clegg, 2012), where participants are first trained on 2 different sequences, and then have to classify a series of unseen sequences according to familiarity. Under *inclusion* instructions, items are to be classified as "old" if they follow either regularity. Under *exclusion* instructions, items are to be classified as "old" if they follow their target sequence, and as "new" if not.

In *artificial grammar learning (AGL)*, participants are exposed to a series of non-word letter strings that are constructed from a complex, finite-state grammar (Reber, 1967). Learning

is measured as the ability to classify unseen letter strings according to grammaticality, and strategic control refers to the ability to apply or withhold grammar knowledge according to instructions. Most methodological procedures for estimating strategic control involve exposure to two different grammars (A vs. B; Dienes, Altmann, Kwan, & Goode, 1995) in two separate training phases. On each trial of a subsequent test phase, participants are presented with letter strings that either follow one of these two grammars or are ungrammatical and follow neither. Participants may be instructed to classify whether new letter strings follow one specified target grammar throughout the test block (Dienes et al., 1995), which can be referred to as a *pure-block procedure* (Norman, Price, & Jones, 2011). Alternatively, one may instruct participants to alternate their classification between the two grammars on a trial-by-trial basis (Norman et al., 2011), referred to as a *mixed-block procedure*; this can be seen as a more demanding test of strategic control in that it requires a moment-by-moment monitoring of both grammars. An alternative procedure developed by Higham, Vokey, and Pritchard (2000) also involves exposure to two grammars. The test phase contains two types of instruction. *In-concert instructions* ask participants to identify strings that are consistent with either grammar as "grammatical", whereas *opposition instructions* ask them to identify only those strings that are consistent with one of the grammars. The assumption here is that opposition, but not in-concert instructions require strategic control. The in-concert condition is largely similar to Dienes et al.'s procedure. A final example is from the neighbouring area of statistical learning. Franco, Destrebecqz, and Cleeremans (2011) presented participants with 2 speech streams generated from two "artificial languages" (L1 and L2). In a discrimination task participants were presented with words from L1, L2, or neither. They either received *inclusion* instructions, which asked them to say "yes" if the word was from either language, or *exclusion instructions*, which asked them to say "yes" if it was from their target language (L1 or L2).

Strategic control and consciousness in implicit learning: Theoretical positions

We will here address some theoretical positions on the relationship between strategic control and consciousness in implicit learning.

Strategic control indicates conscious knowledge. Some would regard strategic control as an indicator of conscious knowledge. In line with the theoretical frameworks of Jacoby (1991) and Baars (1988), measures of strategic control in implicit learning experiments have often been

argued to show that control increases with consciousness – i.e. with the extent to which learning can be considered conscious rather than unconscious. For example, Destrebecqz and Cleeremans (2001) used strategic control during the SRT exclusion task to argue that knowledge was less conscious at lower response-stimulus intervals (RSIs), and more conscious when the interval was higher. Similarly, Wilkinson and Shanks (2004) argued that acquired knowledge was conscious when RSI was set to zero (i.e., RSI-0) on the basis of successful exclusion performance in this condition. Thus, they concluded that sequence learning was explicit rather than implicit. Higham et al. (2000) also included their measure of strategic control with the aim of separating between conscious/controlled influences, on the one hand, and unconscious/automatic influences on the other. However, there is also a handful of studies which specifically address whether knowledge that is not fully conscious can nevertheless be strategically controlled. These have been respectively inspired by the distinction between judgement/structural knowledge and the fringe consciousness framework.

Strategic control can occur with unconscious structural knowledge. A position which sees strategic control as compatible with unconscious knowledge, builds on a distinction between two types of knowledge hypothesised to result from implicit learning. These are *judgement knowledge* of whether or not a certain stimulus complies with the acquired rules, and knowledge of the structure of these rules, i.e., *structural knowledge* (Dienes & Scott, 2005; Scott & Dienes, 2008, 2010). The assumption is that either of these varieties of knowledge could be conscious or unconscious. If structural knowledge is conscious, this will lead to conscious judgement knowledge. However, unconscious structural knowledge could be associated with either conscious or unconscious judgement knowledge. One example is the state of knowing *that* a sentence of one's native language is grammatical but without knowing *why* it is grammatical (Dienes & Scott, 2005). To assess the conscious status of each of the two types of knowledge in an implicit learning experiment, one may ask participants which decision strategy they used when making their classification response. Suggested response alternatives include "random choice", "intuition", "familiarity", "memory" or "rules" (Scott & Dienes, 2008). "Random choice", "intuition", and "familiarity" are assumed to reflect unconscious structural knowledge and therefore defined as "implicit" decision strategies, whereas "memory" and "rules" are commonly referred to as "explicit" decision strategies that are assumed to reflect conscious structural

knowledge. The difference between "random choice", on the one hand, and "intuition" and "familiarity" on the other, is that the former is also associated with unconscious judgement knowledge whereas the latter two are associated with conscious judgement knowledge. In both AGL and SRT experiments, strategic control has been reported even when structural knowledge is unconscious. For example, Wan, Dienes, and Fu (2008) found that participants were able to strategically control the application of two grammars even when they reported using feelings, intuition, or random choice to arrive at their decision. Similarly, Fu, Dienes, and Fu (2010) found successful exclusion ability in an SRT task, even for trials attributed to intuition.

Along similar lines, Norman et al. (2007, 2011) have addressed whether implicit, unconscious knowledge may give rise to intuitive "fringe" feelings that may be strategically controlled (Norman et al., 2007, 2011). Using the terminology of Dienes and Scott (2005), this would refer to a situation of conscious judgement knowledge without conscious structural knowledge. These experiments have focused on whether participants who hold incorrect explicit beliefs about the nature/structure of acquired knowledge, thus indicating that structural knowledge is unconscious, can nevertheless strategically control the application of that knowledge. The implicit learning task must then be set up in a way that allows the participant to develop incorrect beliefs about the rules. This can be done by, e.g., introducing additional random variation in colour and shape of target stimuli, and target position indicators, in an SRT task (Norman et al., 2007). Similarly, random variation can be introduced into the colours and fonts of string elements in AGL (Norman et al., 2011). In an SRT task, Norman et al. (2007) found that even participants who misattributed the nature of the target sequence to irrelevant stimulus properties still showed strategic control over the application of sequence knowledge on a generation rotation task. Similarly, Norman et al. (2011) found that even participants who misattributed the nature of letter regularities to irrelevant string elements, showed strategic control over the application of two grammars in a mixed-block classification task.

Taken together, there is already evidence to show that the application of implicitly learned knowledge can be strategically controlled, even when it can be demonstrated that structural knowledge is unconscious.

Combining measurement procedures to study strategic control over the application of unconscious structural knowledge

Different studies have applied different measurement procedures for estimating whether structural knowledge of artificial grammars is conscious or unconscious. Some studies have measured strategic control among subsets of participants who claim unawareness of the learned rules (Norman et al., 2007, 2011), whereas others have measured it on subsets of trials on which participants report having used decision strategies involving unconscious structural knowledge (Dienes & Scott, 2008; Fu et al., 2010; Wan et al., 2008). Both forms of measurement assess participants' awareness of structural knowledge. However, whereas post-experimental questions about the nature of sequence or grammar rules ask about participants' representation of the *contents* of rule knowledge, decision strategy judgements can be seen to mainly reflect participants' understanding of the extent to which their response involved the *application* of conscious structural knowledge, without assessing the content itself (Norman et al., 2016). Even though it is reasonable to assume that the two measures would most often converge, there might also be exceptions, e.g., when someone reported that they responded on the basis of a conscious rule related to irrelevant stimulus properties. Used in combination the two measures could be seen as a conservative measure of whether conscious structural knowledge is conscious.

One exception is a recent AGL experiment in which we asked participants, in a combined two-step judgement for each classification trial, to indicate (a) their decision strategy (random choice, feelings of intuition/familiarity, or explicit rules/memories) and (b) the relevant stimulus dimension (letter, colour, font) (Norman, Scott, Price, & Dienes, 2016). The rationale for combining the procedures was to provide a robust test of whether unconscious knowledge test can be strategically controlled. If strategic control could be demonstrated in cases where participants both claimed that conscious structural knowledge was not involved, and also attributed their responses to irrelevant stimulus dimensions, this would go against the traditional view of strategic control being indicative of consciousness. However, we did not find strong evidence of strategic control on trials where feelings of intuition/familiarity were attributed to incorrect stimulus dimensions - the data were not sensitive enough to distinguish reliably between possible presence of strategic control and the null hypothesis of no control. Stronger evidence of strategic control was found on trials where the correct stimulus dimension was reported. We therefore speculated that strategic control may require at least global awareness of the nature of the rules, i.e., which stimulus dimension was relevant to the grammaticality judgement. However, a concern is that

trial-by-trial ratings of stimulus dimension may increase participants' conscious hypothesis-testing and prompt their attention toward the correct nature of the rule. Moreover, this procedure may also not necessarily distinguish precisely between *attention to* certain stimulus properties and *awareness of* their importance to the rule. Therefore, these results need to be supplemented by a study in which decision strategies are measured on a trial-by-trial basis (cf. Dienes & Scott, 2005), but where rule awareness is assessed at the end of the experiment (cf. Norman et al., 2011). We now present an experiment that was designed for this purpose.

Method

Participants were 72 Norwegian students (36 females, 36 males) aged 18-33 ($M=21.7$, $SD=3.2$). All participants took part in two training phases, in each of which they were presented with letter strings from a different finite-state grammar (grammar A versus B, order counterbalanced across participants). Grammars and letter strings were taken from Dienes et al. (1995, see Figure 1). The AGL task was programmed in E-prime 2.0 (Schneider, Eschman, & Zuccolotto, 2002a, 2002b) and displayed by a 19" monitor. In each of the two training phases, each of 32 letter strings was presented three times, one at a time, in random order.

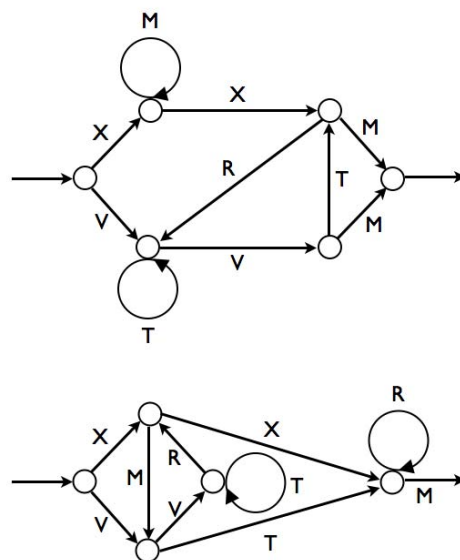


Figure 1

Strings consisted of 5-9 letters (X, V, M, R, T), with each letter written on one of five coloured backgrounds (red, purple, blue, green, or black) and in one of five different fonts (bold, italics, normal, outline, underline). Colour and font of each letter varied randomly between letter strings (see Figure 2). Instructions were to examine each string closely during its 7500 ms display period. To ensure participants attended all 3 stimulus dimensions, a post-trial cue was given on 24 randomly selected trials in each training phase, asking participants to report either the letter (8 trials), colour (8 trials), or font (8 trials) of a randomly chosen string element.

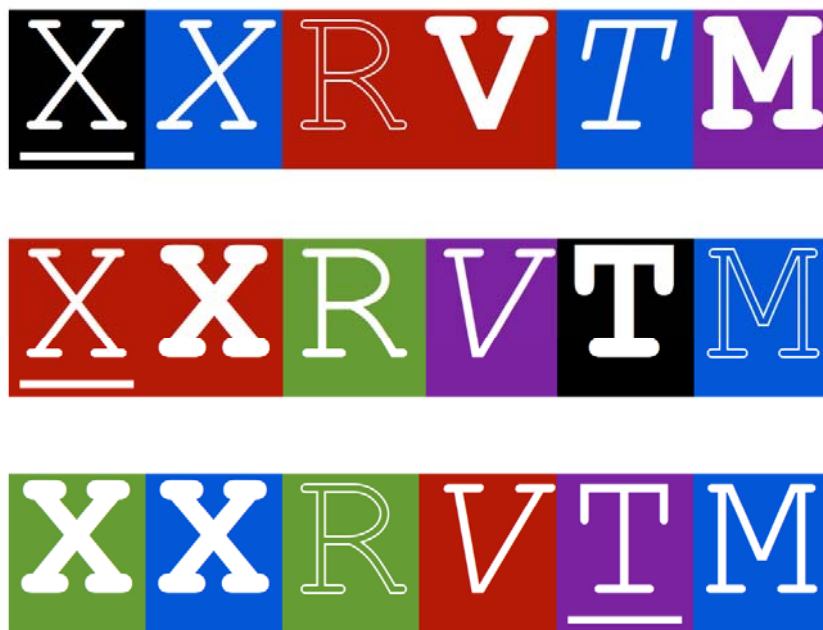


Figure 2

When both training phases were completed, participants were informed that letter strings had been governed by a different complex rule in each phase. They then proceeded to the test phase, which consisted of 60 classification trials. On each trial, three novel letter strings were presented simultaneously in a vertical column – one grammar A string, one grammar B string, and one ungrammatical string. Each string type occurred equally often in each screen position. Following the procedure by Norman et al. (2011), the classification rule, i.e., whether to select the grammar A or grammar B item, varied randomly between individual trials and was indicated

by a written cue ("Rule 1?"/"Rule 2?") displayed above the letter strings (where "Rule 1" referred to the grammar (A or B) that had governed strings during the first training phase, and "Rule 2" to the second grammar (A or B)).

After each classification judgement participants rated their decision confidence on a three-point scale, but these data are not reported. Finally, using the mouse to select from an on-screen list, they indicated whether their response had been based on random choice, intuition, familiarity, rules or memory (Scott & Dienes, 2008). The "implicit" decision strategies of "random choice, intuition, and familiarity" represent claims by participants that they were unaware of the structural aspects of the stimuli that motivated their decision (i.e., there was unconscious structural knowledge). Trials attributed to intuition or familiarity differ from those attributed to random choice because, in the former case, the participant claims to be aware of knowing whether they categorized correctly, even if they do not know why (i.e., judgment knowledge is conscious in the former but not latter case). The "explicit" decision strategies of "rules and memory" represent claims by participants that they were aware of relevant structural properties and indicate that both judgement knowledge and structural knowledge are conscious. (See Dienes 2008, 2012 for further explication of structural and judgment knowledge.)

After the test phase, participants received a questionnaire where they allocated 12 points between the three stimulus dimensions (letter, colour, font) to reflect the extent to which they thought each dimension had contributed to the grammar rules. Conservatively, only participants who allocated 0 points to "letter" were classified as unaware of the nature of the rule, and all others were classified as potentially aware. The frequencies with which participants allocated the distribution of points are presented in Table 1.

Table 1

Number of points allocated to "letters"

	0	1	2	3	4	5	6	7	8	9	10	11	12
N	16	0	0	1	5	0	0	0	5	1	2	0	22

Results

Each participant's degree of strategic control was expressed as a strategic score (Dienes et al., 1995), defined as the proportion of consistent strings chosen out of all consistent and inconsistent strings. A consistent string is one that follows the target grammar and an inconsistent string is one that follows the nontarget grammar.

As analysis of strategic control over grammar knowledge is only meaningful if there is any learning at all, analyses of strategic control only included the 52/72 of participants who chose ungrammatical strings on less than a third of trials. (Note this filter is orthogonal to, and therefore does not artifactually bias, the comparison of the two grammars.) Of these participants, 36 were classified as aware and 16 as unaware of the nature of the rule.

The relationship between strategic control and awareness of the correct rule dimension was examined by comparing strategic scores to a chance level of .5. This was done separately for participants who expressed awareness of the relevance of the letter modality on the post-experimental questionnaire, versus for those who did not. It was also done separately for trials attributed to implicit versus explicit decision strategies. This yielded four conditions. We report effect sizes and Bayes factors in addition to NHST p-values, so that the reader can assess both the strength of evidence and conventional significance levels for any effects (Cumming, 2012; Dienes, 2014, 2015). $B_{H[0,.10]}$ refers to a Bayes factor used to test the hypothesis that strategic scores are above chance level of .5, represented as a half-normal with a SD of .10 above chance level, against the H_0 , the hypothesis of chance performance. The estimated SD of .10 was chosen based on data from a comparable previous study (Norman et al., 2011). A B of 3 or above indicates substantial evidence for the alternative above the null hypothesis, a B of 1/3 or below indicates substantial evidence for the null above the alternative hypothesis, and a B between 1/3 and 3 indicates data insensitivity for distinguishing between the alternative and null hypotheses (Dienes, 2014, 2015). Results are presented in Table 2.

	N*	Strategic score <i>M(SD)</i> $B_H[0,.10]$	t-test compared to chance (.5) <i>t(df)</i> <i>p</i> (2-tailed)	Cohen's effect size <i>d</i>
Aware + implicit strategy	36	.59 (.16) 92.40	3.28 (35) .002	.56
Aware + explicit strategy	29	.61 (.28) 273.98	2.17 (28) .04	.39
Unaware + implicit strategy	16	.55 (.10) 3.10	2.08 (15) .055	.50
Unaware + explicit strategy	12	.51 (.16) .49	.14 (11) .89	.06

* Note: N differs between cells according to how many participants had responses within response category in question.

Table 2

Among participants who correctly attributed grammar rules to the letter dimension (i.e., "aware" participants), the Bayes factor was always above 3, and effect sizes were medium, regardless of whether decision strategy was explicit or implicit. This indicates substantial evidence for the alternative hypothesis above the null hypothesis (Dienes, 2014, 2015), in this case that strategic control was present. T-tests comparing performance to a chance level of .5 also showed that strategic scores were significantly above chance both for trials attributed to implicit and explicit decision strategies. Among participants who did not attribute grammar rules to the letter dimension (i.e., "unaware" participants), the Bayes factor was above 3 and the effect size was medium for implicit decision strategies, supporting the presence of strategic control despite a borderline conventional p-value in a t-test. For explicit decision strategies, the Bayes factor was

between 1/3 and 3 and the effect size was small, which indicates insensitivity for distinguishing between the alternative and the null hypothesis on these trials¹.

Discussion

The key finding of the current experiment was that participants who did not express conscious structural knowledge of two learned grammars nevertheless showed some ability to strategically control the application of those grammars on a trial-by-trial basis. More specifically, strategic control was found on trials where participants claimed to respond on the basis of intuitive feelings, i.e., "implicit" decision strategies. This was the case even among participants who, after the experiment, expressed no awareness of the general nature of the grammars. Instead, they indicated that rules governing strings were related to irrelevant stimulus dimensions. The data therefore support the hypothesis that strategic control may be possible even when structural knowledge is not fully conscious. Our experiment applied two criteria for identifying cases of unconscious structural knowledge, i.e., that participants were not reporting the use of explicit decision strategies to arrive at their classification decisions, and that they expressed unawareness of the general nature of the acquired rules measured by a global rating after the experiment. Even under the combination of these two criteria, participants chose the target grammar more often than the non-target grammar.

Compared to the studies of Dienes et al., (1995) and Wan et al. (2008), our measure of strategic control was very stringent. Participants had to vary the classification rule between trials, which has been argued to require a higher degree of flexible control than if it is only varied between blocks of trials (Norman et al., 2011) because participants need to monitor both grammars on a moment-by-moment basis. Moreover, our criterion for including participants in the "unaware" subgroup was also very conservative, with only those participants who allocated zero points to the correct stimulus dimension being classified as unaware. Even though this implies that the "aware" subgroup may also contain participants who were less than fully aware that the

¹ An ANOVA comparing strategic scores for implicit vs. explicit decision strategies between aware vs. unaware participants showed no significant main effect of awareness [$F(1,39)=1.91$, $p=.28$, $\eta_p^2 = .03$], no significant main effect of decision strategy [$F(1,39)=.11$, $p=.75$, $\eta_p^2 = .002$], and no significant interaction between decision strategy and awareness [$F(1,39)=1.31$, $p=.26$, $\eta_p^2 = .03$].

rule was related to letters alone, it importantly reduces the possibility that the "unaware" subgroup contained participants who believed that the rules were related to letters. It is parsimonious to assume that participants would allocate at least some points to letters if they had even some slight conscious knowledge of the learned rules. Failure to report the stimulus dimension on which the rule was based can therefore be considered a strong indicator that conscious structural knowledge was present.

In sum, our data can be seen to question Jacoby's (1991) general view that strategic control over knowledge requires conscious knowledge, and to also address the more general longstanding debate over whether implicit learning is dependent on conscious awareness of rule fragments (Johnstone & Shanks, 2001; Perruchet & Pacteau, 1990; Redington & Chater, 1996). Even awareness of rule fragments would seem to necessitate awareness of which stimulus dimension mediates the rule. Given that we found grammar knowledge to be expressed without identifying the correct stimulus dimension, it seems implausible that conscious rule fragments can entirely account for artificial grammar learning.

There is nevertheless a concern that participants who were classified as unaware on the post-experiment measure may have been guided by fleeting awareness of letter rules during some trials of the test phase. It could be argued that the reliability of our self-report measure of rule awareness would be improved if measured on a trial-by-trial basis, and that stronger evidence of strategic control over unconscious structural knowledge would be provided if strategic control were found on individual trials that were both rated as implicit and claimed to be specifically related to irrelevant stimulus properties. The only attempt to date at identifying strategic control over unconscious structural knowledge using such a procedure did not find robust evidence for strategic control on individual trials where participants denied the involvement of the relevant dimension. However, care is needed in comparing across studies. Differences in measured awareness across studies that apply different measurement procedures cannot straightforwardly be interpreted in terms of one measure being more sensitive to changes in conscious awareness than another. Certain measurement procedures could potentially also alter what participants are aware of. As pointed out above, measuring rule awareness on a trial-by-trial basis may for instance increase the likelihood that participants explicitly search for rules and become aware of the general nature of the rule. Future studies in this area will have to develop trial-by-trial measurement procedures that are less likely to interfere with people's hypothesis-testing, and that

more adequately distinguish between *attention* to certain stimulus properties and *awareness* of their involvement in the rule, which is another limitation with this procedure.

Our current procedure did use a trial-by-trial measure, namely the structural knowledge attributions. Even with a trial-by-trial measure, noise will produce some misclassification. However the percentage of trials classified as involving unconscious structural knowledge was 68.80 for participants aware of the relevant stimulus dimension, and 85.93 for participants unaware of the relevant stimulus dimension. It is unlikely that measurement noise, or biased responding by participants, could explain such a large proportion of responses, involving a similar level of strategic knowledge as for responses classified as involving conscious strategic knowledge (both .58).

Although the current data supported the hypothesis that strategic control does not require conscious structural knowledge, more studies are needed to specifically address whether strategic control may require conscious judgement knowledge, i.e., conscious knowledge of *whether or not* a certain letter string is grammatical (Dienes & Scott, 2005). This kind of knowledge in which people are aware that a stimulus belongs to a given category, without having conscious access to the antecedents of the knowledge, has also been referred to as intuitive cognitive feelings (Norman & Price, 2010; Price & Norman, 2008, 2009) or fringe consciousness (Norman, Price, & Duff, 2006, 2010; Norman et al., 2007). Since, for statistical reasons, the three implicit response categories ("random choice", "intuition", and "familiarity") were combined in the current experiment, this question cannot be addressed from the current data.

As expected, participants who were aware that the rules were related to letters, showed strategic control on trials where they claimed to apply "explicit" strategies. This is consistent with previous findings showing that knowledge which is consciously accessible and attributed to the correct source can be strategically controlled (Jacoby, 1991). Strategic control was also found when these participants classified their responses as related to the correct stimulus dimension but as nevertheless based on "implicit" decisions. Strategic control was not found when participants who were generally unaware of the correct stimulus dimension rated their classification decision as "explicit". This is expected if participants based their responses on incorrect, explicit hypotheses related to irrelevant stimulus properties, and therefore supports the validity of the self-report ratings of decision strategy.

Rünger and French (2010) have argued that verbal reports are sensitive measures of consciousness in implicit learning, but only for measures reflecting the content of learning (e.g., our ratings of relevant stimulus dimension) and not metacognitive judgments (e.g., our ratings of explicit versus implicit decision strategy) which they argue are less sensitive and less informative. The current study shows the usefulness of both forms of verbal report measure and exemplifies how the two types of measurements may complement each other in AGL experiments.

References

- Baars, B. J. (1988). *A cognitive theory of consciousness*. New York, NY: Cambridge University Press.
- Cumming, G. (2012). *Understanding the new statistics: Effect sizes, confidence intervals, and meta-analysis*. New York: Routledge.
- 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
- Dienes, Z. (2014). Using Bayes to get the most out of non-significant results. *Frontiers in Psychology*, 5. doi: 10.3389/fpsyg.2014.00781
- Dienes, Z. (2015). How Bayesian statistics are needed to determine whether mental states are unconscious. In M Overgaard (Ed.), *Behavioral Methods in Consciousness Research* (pp. 199-220). London, UK: Oxford University Press.
- Dienes, Z., Altmann, G. T. M., 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., & Perner, J. (2007). Executive control without conscious awareness: the cold control theory. In G. Jamieson (Ed.), *Hypnosis and conscious states: The cognitive neuroscience perspective* (pp 293-314). Oxford University Press.
- 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
- Franco, A., Cleeremans, A., & Destrebecqz, A. (2011). Statistical learning of two artificial languages presented successively: how conscious? *Frontiers in Psychology*, 2, 229. doi: 10.3389/fpsyg.2011.00229
- Fu, Q., Dienes, Z., & Fu, X. (2010). Can unconscious knowledge allow control in sequence learning? *Consciousness and Cognition*, 19(1), 462–474. doi:10.1016/j.concog.2009.10.001
- Fu, Q., Fu, X., & Dienes, Z. (2008). Implicit sequence learning and conscious awareness. *Consciousness and Cognition*, 17, 185-202. doi:10.1016/j.concog.2007.01.007
- Goschke, T. (1998). Implicit learning of perceptual and motor sequences: Evidence

- for independent learning systems. In M. A. Stadler & P. A. Frensch (Eds.), *Handbook of Implicit Learning* (pp. 401–444). Thousand Oaks, CA: Sage Publications.
- Hepler, J., & Albarracín, D. (2013). Complete unconscious control: Using (in) action primes to demonstrate completely unconscious activation of inhibitory control mechanisms. *Cognition*, *128*(3), 271–279. doi: [10.1016/j.cognition.2013.04.012](https://doi.org/10.1016/j.cognition.2013.04.012)
- Higham, P. A., Vokey, J. R., & Pritchard, J. (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
- Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language*, *30*(5), 513–541. doi:10.1016/0749-596X(91)90025-F
- Johnstone, T., & Shanks, D. R. (2001). Abstractionist and processing accounts of implicit learning. *Cognitive Psychology*, *42*, 61–112.
- Lau, H. C., & Passingham, R. E. (2007). Unconscious activation of the cognitive control system in the human prefrontal cortex. *The Journal of Neuroscience*, *27*(21), 5805–5811. doi 10.1523/JNEUROSCI.4335-06.2007
- Lau, H., & Rosenthal, D. (2011). Empirical support for higher-order theories of conscious awareness. *Trends in Cognitive Sciences*, *15*(8), 365–373.
- Mangan, B. (2001). Sensation's ghost: The non-sensory "fringe" of consciousness. *Psyche*, *7*(18), URL: <http://psyche.cs.monash.edu.au/v7/psyche-7-18-mangan.html>.
- 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: 10.5709/acp-0107-z
- Nissen, M. J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology*, *19*, 1–32. doi:10.1016/0010-0285(87)90002-8
- Norman, E. (2015). Measuring strategic control in implicit learning: How and why? *Frontiers in Psychology: Consciousness Research*, *6*:1455. doi: 10.3389/fpsyg.2015.01455
- Norman, E., Price, M. C., & Duff, S. C. (2006). Fringe consciousness in sequence learning: The influence of individual differences. *Consciousness and Cognition*, *15*(4), 723–760.

- Norman, E., Price, M. C., & Duff, S. C. (2010). Fringe consciousness: A useful framework for clarifying the nature of experience-based feelings. In A. Efklides og P. Misailidi (Eds.). *Trends and Prospects in Metacognition Research*, pp. 63-80, New York, NY: Springer.
- Norman, E., Price, M. C., Duff, S. C., & Mentzoni, R. A. (2007). Gradations of awareness in a modified sequence learning task. *Consciousness and Cognition*, *16*, 809-837. doi:10.1016/j.concog.2007.02.004
- Norman, E., Price, M. C., & Jones, E. (2011). Measuring strategic control in artificial grammar learning. *Consciousness and Cognition*, *20*, 1920-1929. doi:10.1016/j.concog.2011.07.008
- Norman, E., Scott, R. B., Price, M. C., & Dienes, Z. (2016). The relationship between strategic control and conscious structural knowledge in artificial grammar learning. *Manuscript submitted for publication*.
- Perruchet, P., & Pacteau, C. (1990). Synthetic grammar learning: Implicit rule abstraction or explicit fragmentary knowledge? *Journal of Experimental Psychology: General*, *119*(3), 264-275.
- Price, M. C., & Norman, E. (2008). Intuitive decisions on the fringes of consciousness: Are they conscious and does it matter? *Judgment and Decision Making*, *3*, 28-41.
- Price, M. C., & Norman, E. (2009). Cognitive Feelings. In T. Bayne, A. Cleeremans, & P. Wilken, (Eds.), *Oxford Companion to Consciousness*, pp.141-144. Oxford: Oxford University Press.
- Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior*, *77*, 317-327. doi:10.1016/S0022-5371(67)80149-X
- Redington, M., & Chater, N. (1996). Transfer in artificial grammar learning: A reevaluation. *Journal of Experimental Psychology: General*, *125*(2), 123-138.
- Rosenthal, D.M. (2005). *Consciousness and Mind*, Clarendon Press.
- Rünger, D., & Frensch, P. A. (2010). Defining consciousness in the context of incidental sequence learning: Theoretical considerations and empirical implications. *Psychological Research*, *74*, 121-137.
- Schmidt, J. R., Crump, M. J. C., Cheesman, J., & Besner, D. (2007). Contingency learning

- without awareness: Evidence for implicit control. *Consciousness and Cognition*, *16*(2), 421-435. doi: 10.1016/j.concog.2006.06.010
- Schneider, W., Eschman, A., & Zuccolotto, A. (2002a). *E-Prime Reference Guide*. Pittsburgh, PA: Psychology Software Tools Inc.
- Schneider, W., Eschman, A., & Zuccolotto, A. (2002b). *E-Prime User's Guide*. Pittsburgh, PA: Psychology Software Tools Inc.
- Scott, R., & Dienes, Z. (2010). The metacognitive role of familiarity in artificial grammar learning: Transitions from unconscious to conscious knowledge. In A. Efklides and P. Misailidi (Eds.). *Trends and prospects in metacognition research* (pp. 37-61). New York, NY: Springer.
- Scott, R. B., & Dienes, Z. (2008). The conscious, the unconscious, and familiarity. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(5), 1264–1288. doi: 10.1037/a0012943
- Van Gaal, S., Ridderinkhof, K. R., Scholte, H. S., & Lamme, V. A. F. (2010). Unconscious activation of the prefrontal no-go network. *The Journal of Neuroscience*, *30*(11), 4143-4150. doi:10.1523/JNEUROSCI.2992-09.2010
- Wan, L., Dienes, Z., & Fu, X. (2008). Intentional control based on familiarity in artificial grammar learning. *Consciousness and Cognition*, *17*(4), 1209–1218. doi:10.1016/j.concog.2008.06.007
- 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

Author note

This research was supported by a project grant from the Meltzer foundation. We thank Oskar Blakstad for his contributions in programming the experiment.