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The speed of metacognition: Taking time to get to know one's structural knowledge

Andy D. Mealor *, Zoltan Dienes

Sackler Centre for Consciousness Science and the School of Psychology, University of Sussex, UK

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ABSTRACT

The time course of different metacognitive experiences of knowledge was investigated using artificial grammar learning. Experiment 1 revealed that when participants are aware of the basis of their judgments (conscious structural knowledge) decisions are made most rapidly, followed by decisions made with conscious judgment but without conscious knowledge of underlying structure (unconscious structural knowledge), and guess responses (unconscious judgment knowledge) were made most slowly, even when controlling for differences in confidence and accuracy. In experiment 2, short response deadlines decreased the accuracy of unconscious but not conscious structural knowledge. Conversely, the deadline decreased the proportion of conscious structural knowledge in favour of guessing. Unconscious structural knowledge can be applied rapidly but becomes more reliable with additional metacognitive processing time whereas conscious structural knowledge is an all-or-nothing response that cannot always be applied rapidly. These dissociations corroborate quite separate theories of recognition (dual-process) and metacognition (higher order thought and cross-order integration).

1. Introduction

What is the difference in the nature of conscious and unconscious knowledge? Artificial grammar learning (AGL; Reber, 1967) is a particularly useful methodology to help address this question as it demonstrably elicits both conscious and unconscious knowledge according to subjective measures of awareness (e.g. Dienes, 2008a; Gaillard, Vandenberghe, Destrebecqz, & Cleeremans, 2006; Johansson, 2009). Two types of knowledge are involved in sequence classification in AGL: structural knowledge and judgment knowledge (Dienes & Scott, 2005; Scott & Dienes, 2008). During the initial training phase of a typical AGL experiment, participants are exposed to rule-based sequences generated by the grammar in question. Structural knowledge is (either conscious or unconscious) knowledge of the structural consequences of the grammar and can consist of, for example, rules, patterns of connection weights, chunks, or whole items taken as examples of the structure learned during training. Before testing, participants are informed the sequences were generated by a series of complex rules before going onto classify further novel sequences in terms of their grammaticality (whether they conform to or violate the studied rules; typically 50% of sequences are grammatical at test). Here, judgment knowledge is the (conscious or unconscious) knowledge constituted by such a judgment which is directly expressed in sequence classification (i.e. the knowledge that the test item is or is not grammatical). When both structural and judgment knowledge are conscious, grammaticality decisions are based on hypothesis-driven rule-application or a conscious recollection process of recognised exemplars or bigrams, trigrams or other parts of exemplars encountered during training. Feelings of intuition or familiarity are expressed

* Corresponding author. Address: School of Psychology, University of Sussex, Falmer, Brighton BN1 9QH, UK. Fax: +44 1273 678058.
E-mail address: a.d.mealor@sussex.ac.uk (A.D. Mealor).

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when structural knowledge is unconscious but judgment knowledge is conscious (e.g.: "I know I'm correct but I don't know why") (Norman, Price, & Duff, 2006; Norman, Price, Duff, & Mentzoni, 2007). When both knowledge types are unconscious the phenomenology is that grammar judgments are mere guesses; no conscious metaknowledge of what has been learned is expressed. (See Scott & Dienes, 2010a, for a model of how structural and judgment knowledge develop in AGL; and Scott & Dienes, 2008, and Pasquali, Timmermans, & Cleeremans, 2010, for models of how judgment knowledge may become conscious. See Fig. 1 for the relationship between the conscious status of knowledge types and the associated phenomenology.)

Numerous subjective measures of awareness have been used in AGL studies including verbal reports (Reber, 1967, 1969); confidence ratings made on binary (Tunney & Shanks, 2003) or continuous scales (Dienes, Altmann, Kwan, & Goode, 1995); structural knowledge attributions (Dienes & Scott, 2005; Scott & Dienes, 2008; Scott & Dienes, 2010a, 2010b, 2010c, 2010d; Wan, Dienes, & Fu, 2008; see also Chen et al., 2011; Guo et al., 2011; Rebuschat & Williams, 2009) and wagering high or low amounts to indicate high or low levels of conscious awareness (Persaud, McLeod, & Cowey, 2007). Recently, a new form of wagering as a measure of awareness has been introduced into the AGL literature to indicate the presence of unconscious knowledge, namely 'no-loss gambling' (Dienes & Seth, 2010). During the test phase of AGL studies using the no-loss gambling procedure, participants indicate confidence (thus, metacognitive awareness) in their grammaticality decisions by either betting on their decision and, if correct they gain a reward (e.g.: one sweet), or they can gain a reward by betting on a transparently random process with a 50% chance of winning. If one chooses to bet on the random process, rather than on the grammaticality decision, one is not aware of knowing the grammaticality of the stimulus, as it feels as if the grammaticality judgment is as reliable as flipping a coin (i.e.: it is a guess response). Conversely, when betting on the grammar decision itself, some degree of confidence and hence metacognitive awareness is indicated. Dienes and Seth found that when participants were betting on the random process, the accuracy of their grammaticality judgments was significantly above chance (around 60% correct), satisfying the guessing criterion of unconscious knowledge (Dienes et al., 1995). This shows participants could express unconscious structural knowledge when judgment knowledge was unconscious.

Mealor and Dienes (2012a) used the no-loss gambling method to investigate an apparent contradiction in dual-process theories of recognition memory. Dual-process theories posit that responses based on familiarity are made rapidly and automatically whereas recollection responses are relatively effortful and time-consuming due to strategic retrieval (e.g.: Jacoby, 1991; Yonelinas, 2002; see also the two-stage recollection hypothesis of Moscovitch, 2008, and the continuous dual-process model of Wixted & Mickes, 2010). Several researchers have found evidence to support this view (e.g. Boldini, Russo, & Avons, 2004; Coane, Balota, Dolan, & Jacoby, 2011; Feredoes & Postle, 2010; Gronlund & Ratcliff, 1989; Hintzman & Caulton, 1997; McElree, Dolan, & Jacoby, 1999; Yonelinas & Jacoby, 1996). However, studies using the remember-know methodology (R/K; Tulving, 1985) have provided contradictory evidence. R/K studies involve a learning phase where participants are presented with to-be-remembered stimuli (typically word lists). At test, they are required to discriminate between these previously seen targets and novel lures. When endorsing a stimulus as previously seen, the phenomenological basis for that decision is also reported; either remember (R) responses which indicate conscious recollection; know (K) responses which indicate a feeling of familiarity without conscious recollection that the stimulus had been presented earlier; or guess (G) responses which indicate no feeling of memory at all even though the test item is accepted as old. Using this methodology, several researchers have found that in self-paced tests, R responses to endorsed stimuli are made most rapidly, followed by K responses and then G responses (e.g.: Dewhurst & Conway, 1994; Dewhurst, Hitch, & Barry, 1998; Dewhurst, Holmes, Brandt, & Dean, 2006; Duarte et al., 2007; Henson, Digg, Shallice, Josephs, & Dolan, 1999; Konstantinou & Gardiner, 2005; Wheeler &

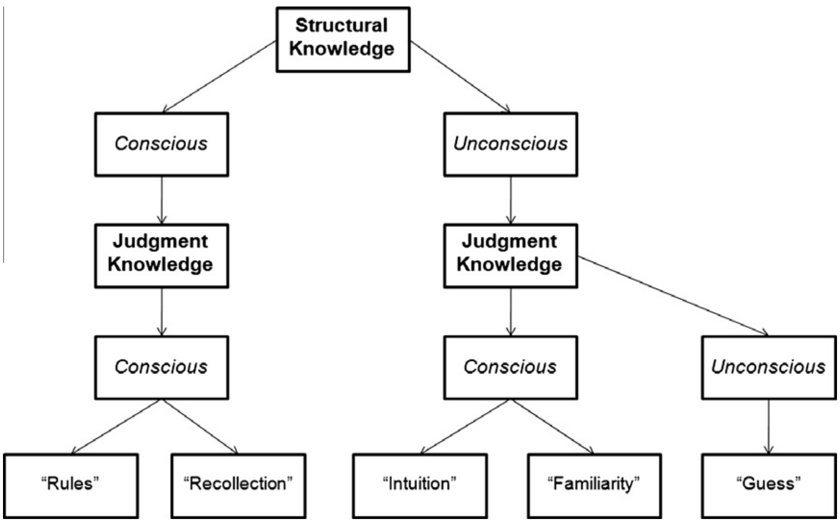

Fig. 1. The relationship between the conscious status of structural and judgment knowledge. The bottom row represents self-reported structural knowledge attributions (Dienes and Scott, 2005; Scott and Dienes, 2008).

Buckner, 2004; see also Sheldon & Moscovitch, 2010). The Dewhurst et al. (2006) interpretation of these findings is that RTs may not reflect the direct times of the actual retrieval process *per se*, but rather the information R, K and G responses afford to metaknowledge. A recollective experience allows a response without further delay, but a feeling of familiarity may be probed further.

The R/K method as applied to memory presumably taps into similar underlying processes as recollection and familiarity as AGL (see Tunney, 2007, for implementation of R, K and G responses in an AGL task). Many researchers (but not all, e.g. Donaldson, 1996; Dunn, 2004) subscribe to the view that R and K responses reflect qualitatively different forms of metacognitive commitment to a current test item having been previously presented. In a similar manner, recollection and familiarity in AGL reflect different metacognitive experiences that the current test sequence conforms to or violates the grammar structure from training. R responses in R/K and rules/recollection responses in AGL are consequents of consciously recognising the current item, or parts of the sequence, from training. K responses are given when there is a feeling of 'oldness' that the item has been presented previously without recollecting its occurrence and in AGL, intuition/familiarity responses are given when some aspect(s) of the test sequence result in a feeling of grammaticality or ungrammaticality ('oldness'/'newness' in an abstract sense of the current item's structure being old) but without consciously identifying those aspects that led to that feeling. The interpretation of guess responses in both paradigms is also similar. Wixted and Mickes (2010) state that G responses are made when the memory strength of an item falls near the old/new decision criterion. In AGL, guess responses are made when the subjective familiarity of a to-be-classified sequence is close to mean subjective familiarity of previously encountered sequences acquired during the course of the experiment (Scott & Dienes, 2008, 2010a). However, a meta-analysis by Gardiner, Ramponi, and Richardson-Klavehn (2002) concluded that the accuracy of guess responses in R/K studies is typically at chance. This is not true of AGL studies where the guessing criterion is often satisfied (e.g.: Dienes & Altmann, 1997; Dienes & Scott, 2005; Dienes & Seth, 2010; Dienes et al., 1995; Tunney & Shanks, 2003). Furthermore, it has been shown that subjective familiarity can influence grammaticality judgments when participants report their decision strategy as a random selection (Scott & Dienes, 2008) which makes AGL an ideal procedure to investigate the respective time-courses of these different types of response.

Using the no-loss gambling method, Mealor and Dienes (2012a) showed that in self-paced tests, 'guess' responses (as shown by willingness to bet on the 50:50 random process) took longer than responses made with some degree of conscious judgment knowledge (as shown by willingness to bet on the grammaticality decision) even when differences in accuracy were accounted for. In a second study, a strict response deadline (500 ms) was introduced into the test phase. It was found that the deadline only reduced the quality of responses made with conscious judgment knowledge and had no detectible effect on the quality of guess responses. Thus, it was concluded participants await a metacognitive feeling of judgment (e.g.: recollection or familiarity) to form. If this feeling is not forthcoming, only then do people opt to guess, i.e.: long RTs for guess responses are a reflection of the information afforded to metaknowledge (Dewhurst et al., 2006). However, when externally enforced, guess responses do not suffer a speed-accuracy trade off, which is not true of decisions made with some degree of metacognitive awareness. In the context of AGL this means that when both structural and judgment knowledge are unconscious, the decision quality is as good as it will ever be in around 500 ms (for the materials used in Mealor and Dienes) but when judgment knowledge is conscious, extra time is needed to optimise the decision. It was also found that participants attempted to apply conscious judgment (shown by the proportion of bets on the grammar decision to bets on the random process) in as many short deadline trials as no deadline trials showing that the process of metacognitive judgment has at least started in around 500 ms, but time is needed for that process to become optimally reliable (i.e.: under a deadline, participants think they are using a reliable judgment process to guide sequence classification when the reliability of that process has become compromised). However, as bets on the grammar decision in no-loss gambling do not distinguish between conscious and unconscious structural knowledge (i.e.: between intuition/familiarity and rules/recollection as shown on Fig. 1), the findings of Mealor and Dienes raise further questions: is it conscious or unconscious structural knowledge that takes time to be applied? And what can we infer about the nature of the decision processes based on conscious and unconscious structural knowledge through investigating their time courses? We address these questions in two AGL experiments using self-paced responding (experiment 1) and response deadlines (experiment 2).

2. Experiment 1

Experiment 1 aimed to replicate and extend the findings of Mealor and Dienes (2012a) using structural knowledge attributions in lieu of no-loss gambling (see Section 3.3 for the structural knowledge attribution definitions used in the current experiments). These attributions allow for a greater range of responding when participants have some degree of confidence (metacognitive awareness) in their grammaticality decision and allow inference of the conscious status of structural knowledge subsumed within these decisions. As AGL and R/K presumably tap into similar decision making process, it is predicted that responses based on conscious structural knowledge (rules, recollection) should be most rapid, followed by those based on unconscious structural knowledge accompanied by conscious judgment knowledge (intuition, familiarity) and finally decisions made without conscious judgment knowledge (random selection, i.e.: guess responses).

Confidence is also inversely related to RT (e.g.: Petrusic & Baranski, 2003, 2009; Tunney & Shanks, 2003) and decisions based on familiarity or intuition are accompanied by lower confidence estimates than those based on rules or recollections whereas guesses are, by definition, made in the absence of confidence (e.g.: Dienes & Scott, 2005). This is also the pattern we would expect to observe in self-paced R/K studies (e.g.: Dewhurst et al., 2006). Theories which postulate (and methodologies which presume through their operationalisation) a qualitative difference between conscious and unconscious knowledge need to show that these reported types of knowledge are not reducible to a single dimension, such as confidence. If guesses, familiarity-based responding and recollection-based responding are associated with differing levels of accuracy and subjective confidence, this could be problematic for such theories. Thus, a second aim of experiment 1 was to determine whether these response types have a degree of independence in terms of the time it takes to make a decision based on such knowledge types once confidence and accuracy are accounted for.

3. Method

3.1. Design and participants

Fifty-five University of Sussex undergraduates participated in this study (ages ranged from 18 to 45 years). The two grammar cross-over design of Dienes and Altmann (1997) was used. Participants were trained and tested on either grammar A or B acting as control groups for one another. During testing, sequences from grammar A were used as ungrammatical sequences for grammar B and vice versa.

3.2. Materials

The set of testing and training sequences were the same as used by Dienes and Scott (2005, Experiment 2) and Mealor and Dienes (2012a). Sequence length was between five and nine characters. The training lists were comprised of 15 training sequences from the respective grammar, combined and repeated three times in a random order. Thirty novel testing sequences from each grammar were used, again combined in a random order meaning participants viewed 60 testing sequences, 50% of which conformed to their respective training grammar. A fixed counterbalanced order was used in training and testing. EPrime 2.0 software was used to display the stimuli and record responses.

3.3. Procedure

Participants were tested individually at a computer. During the training phase, the sequences appeared centrally in black text (font Arial, point size 66) for 5000 ms followed by a blank screen for 5000 ms. During this time the participant was required to write down the sequence as accurately as possible on a provided piece of paper before the next sequence appeared. The paper was removed after all 45 training sequences had been copied. Participants were then informed the sequences obeyed a complex set of rules and they were to classify further novel sequences in terms of grammaticality, half of which obeyed the same rules just studied. Each testing sequence required three judgments: grammaticality, attribution and confidence. For the grammaticality decision, participants indicated their choice by pushing the 1 (yes – the sequence is grammatical and conforms to the rules) or 0 key (no – the sequence is not grammatical and does not conform to the rules). RTs to this decision were recorded. Secondly, they were asked from where they felt their response arose (knowledge attribution) from five options based on Scott and Dienes (2008), corresponding to five numbers on the keyboard: random selection (1), intuition (3), familiarity (5), rules (7), recollection (9). The definition of these categories was as follows: *Random selection* – There is no basis for your response whatsoever. You may as well have flipped a coin to decide (this response corresponds to 50% confidence). *Intuition* – You feel your response is correct but have no idea why. *Familiarity* – Your response is based on a feeling of something seen earlier, or a feeling that something has changed or is missing, but you have no idea what. *Rules* – Your response is based on some rule(s) you learned earlier and you could say what these rules are if asked. *Recollection* – Your response is based on the fact you could or could not recollect seeing (parts of) the sequence earlier. Finally they were asked to enter their confidence in their grammar judgment choosing any number between 50% (a complete guess) and 100% (completely certain). Random selection responses were only allowed a value of 50% confidence. Participants were provided with a booklet of these definitions which they were allowed to refer to for knowledge attribution and confidence input. Once participants had given these responses for all 60 test sequences, the experiment was over.

4. Results

Responses based on familiarity or intuition were pooled into an ‘unconscious structural knowledge’ category; rules and recollection responses were pooled into a ‘conscious structural knowledge’ category; random selection responses (henceforth ‘guesses’) are responses based on unconscious structural and judgment knowledge and as such form their own category (the crucial difference between this response type and the unconscious structural knowledge category is that guesses are made without conscious judgment knowledge. The category labels used here are for the sake of brevity). See Table 1 for the percentage of response types. All *t*-tests in both experiments are reported with two-tailed significance unless specifically stated otherwise. Note the degrees of freedom change slightly between tests: not all participants used all attributions during testing so could not be entered into the corresponding analyses.

Table 1
Percentage of responses, proportion of correct responses and response times (RTs) for knowledge categories in experiment 1. Standard errors appear in parentheses.

	Guess	Unconscious structural knowledge	Conscious structural knowledge
Responses	12% (2.00)	54% (2.94)	34% (3.12)
Accuracy	.59 (.04)	.72 (.02)	.80 (.02)
RT (ms)	6571 (389)	4772 (175)	3996 (153)

4.1. Accuracy of knowledge types

Accuracy scores (see Table 1) were entered into a one-way repeated measures ANOVA, finding a significant main effect of response type, $F(2,82) = 19.04$, $p < .001$. Bonferroni adjusted pairwise comparisons showed that unconscious structural knowledge responses were significantly more accurate than guesses, $p = .004$. Conscious structural knowledge responses were significantly more accurate than both guesses, $p < .001$, and unconscious structural knowledge responses, $p = .004$, showing conscious judgment of both conscious and unconscious structural knowledge according to the zero correlation criterion. A robust Friedman's ANOVA was also conducted, and followed up with Wilcoxon signed ranks tests to determine between category differences, revealing the same pattern as the parametric tests (all $ps < .002$). The mean accuracy of guesses was above the chance value of .50, $t(45) = 2.54$, $p = .015$, satisfying the guessing criterion of unconscious knowledge. Similarly, accuracy was above chance for both unconscious structural knowledge, $t(53) = 12.43$, $p < .001$, and conscious structural knowledge, $t(48) = 12.78$, $p < .001$, showing conscious judgment knowledge according to the zero correlation criterion.

4.2. Response times

RT data were *z*-transformed and outliers 2 *SD* beyond the mean were removed prior to analyses (<1.6% data removed per knowledge category; see Table 1). Kolmogorov–Smironov tests showed the distributions of RT data for all response types were not detectibly different from normality, $Ds \leqslant .131$, $ps \geqslant .067$. Mean RT of conscious structural knowledge was 3996 ms ($SE = 153$); for unconscious structural knowledge, mean RT was 4772 ms ($SE = 175$); and for guesses mean RT was 6571 ms ($SE = 389$). (Note: RT data presented ignore accuracy). A one-way repeated measures ANOVA was conducted on RTs ($N = 42$) finding a significant effect of response type, $F(2,92) = 42.70$, $p < .001$. Bonferroni adjusted pairwise comparisons revealed guesses to be significantly more time consuming than both conscious and unconscious structural knowledge responses, $ps < .001$. Unconscious structural knowledge responses also took longer to be expressed than conscious ones, $p < .001$. A robust Friedman's ANOVA was also conducted, and followed up with Wilcoxon signed ranks tests, revealing the same pattern as the parametric tests (all $ps < .001$).

Mean confidence in conscious structural knowledge responses was 76% ($SE = 1.14$) and 66% ($SE = 0.95$) in unconscious structural knowledge responses. The difference was significant, $t(48) = 10.92$, $p < .001$, and both were significantly higher than the 50% confidence associated with guess responses, $ts > 16.60$, $ps < .001$. Therefore it could be the case that the RT difference between response types is reducible to different levels of confidence. To determine whether knowledge attribution made a unique contribution to RT of responses beyond confidence, multiple regression analyses were conducted according to Lorch and Myers's (1990) individual equation method. Response type was dummy coded (using guesses as a baseline, i.e. one variable coded guesses 0, unconscious structural knowledge 0 and conscious structural knowledge 1; another variable coded guesses 0, unconscious structural knowledge 1, and conscious structural knowledge 0) which was used to predict RT while controlling for confidence and accuracy. Accuracy was not a significant predictor of RT, $\beta = -.02$ ($SE = .03$), $t(41) = 0.74$, $p = .462$, 95% CI [−.08, .03]. Confidence was a significant predictor of RT, $\beta = -.18$ ($SE = .03$), $t(41) = 6.46$, $p < .001$. After controlling for accuracy and confidence, unconscious structural knowledge was found to be significantly faster than guessing, $\beta = -.24$ ($SE = .06$), $t(41) = 4.10$, $p < .001$. Similarly, after controlling for accuracy and confidence, conscious structural knowledge responses were also found to be significantly faster than guessing, $\beta = -.29$ ($SE = .07$), $t(41) = 4.33$, $p < .001$. The difference between the standardised beta coefficients of conscious and unconscious structural knowledge responses was also significant, $t(41) = 2.09$, $p = .043$, confirming the RT difference between guess, unconscious and conscious structural knowledge responses held once accuracy and confidence were accounted for.

5. Discussion

Responses based on conscious structural knowledge (rules, recollection) were made more rapidly than those based on unconscious structural knowledge accompanied by conscious judgment knowledge (intuition, familiarity), which in turn were made more rapidly than guesses (random selection). Multiple regression analysis confirmed that this effect held when both differences in confidence and accuracy were accounted for showing that these types of knowledge attributions are not reducible to a single dimension of confidence in terms of the time taken to express underlying structural knowledge (contrast the interpretations of confidence and RT in R/K studies proposed by Dewhurst et al., 2006, and Rotello & Zeng, 2008; see also Ratcliff & Starns, 2009; Rotello, Macmillan, & Reeder, 2004). These results replicate and extend those of Mealor and Dienes (2012a; see also Scott & Dienes, 2008; Scott & Dienes, 2010b). Using the no-loss gambling method, it was unclear whether conscious or unconscious structural knowledge (accompanied with some degree of confidence) is expressed more rapidly in self-paced tests. These results show that it is conscious structural knowledge, followed by unconscious structural knowledge accompanied by conscious judgment and finally judgments made in the absence of any conscious preference for grammaticality.

6. Experiment 2

Self-paced tests show that, when judgment knowledge is conscious, underlying unconscious structural knowledge takes longer to be expressed than conscious structural knowledge. However, it could be the case that the time differences do not reflect the time courses of those structural knowledge types *per se*, but rather the way they are used by metacognitive processes (consistent with the interpretation of dual process theory of e.g. Dewhurst et al., 2006). Mealor and Dienes (2012a, experiment 2) found that short response deadlines (500 ms) only impacted on the quality of responses made with some degree of confidence. However, the no loss gambling method does not allow us to infer the conscious status of structural knowledge when participants bet on their grammar decision. Therefore, it is unclear whether the reduction in quality of these responses was due to difficulties in utilising conscious or unconscious structural knowledge under the deadline. We consider two opposing theories for the effect of deadlines on conscious vs. unconscious knowledge.

On the one hand, dual-process theory suggests that consciously applying remembered rules may be relatively effortful (particularly if the rules held are fairly complex) compared to using automatic familiarity processes to classify sequences, thus making rule application a time consuming process. This possibility allows us to derive the hypothesis that a short response deadline would interfere with judgments based on rules or recollections, either via reduced accuracy of those decisions and/or via a decrease in the overall proportion of responses attributed to rules or recollection as participants simply would not have time to apply their conscious structural knowledge (and consequently, there would be an increase in attributions reflecting unconscious structural knowledge).

On the other hand, when structural knowledge is conscious, it is symbolic in nature meaning there is relatively little noise in the representation and the grammaticality decision is binary (e.g.: "I have (not) encountered XRV before, therefore the sequence is (not) grammatical") (cf. Sun, 2002). Thus, conscious rules maybe resistant to noise in that they can be easily cleaned up. In contrast, when structural knowledge is unconscious, the familiarity signal it affords to metacognitive judgment is a continuous, non-symbolic representation. Adopting a higher-order thought theory position (Rosenthal, 2000), it could be the case that this familiarity signal is vulnerable to interruption before the higher order process (conscious judgment) has settled and a decision is made. This higher order state would therefore misrepresent the lower order state (unconscious structural knowledge). A similar prediction can be derived from cross-order integration theory (Kriegel, 2005, 2007). If the lower and higher order states are linked by re-entrant loops (Edelman, 1989; Lamme, 2006), the deadline manipulation may interfere with the metacognitive process which would modify the lower order state, distorting the stored unconscious structural knowledge and lowering accuracy of this response type. These two possibilities effectively result in the same behavioural prediction that response deadlines would actually harm the accuracy of decisions based on unconscious structural knowledge. Furthermore, as participants would, by definition, be unaware that their unconscious structural knowledge had become distorted, or misrepresented by their higher order judgment, the deadline manipulation would be unlikely to decrease the proportion of familiarity responses in favour of random responding (note that a deadline would not increase rule-based or recollective responding; the self-paced responding of experiment 1 shows that no matter how much time is given to classify a particular sequence unconscious structural knowledge does not, itself, become conscious). The primary aim of experiment 2 was to distinguish these theories of the effect of deadlines on conscious and unconscious structural knowledge. Would deadlines harm unconscious structural knowledge more than conscious or vice versa?

One important methodological factor to consider is the presence or absence of the grammar sequence during the testing phase. Conscious mental states about grammaticality may be relatively transient and could degrade between the grammaticality decision and knowledge attribution. However, a concurrent grammaticality and attribution design would be impractical when using five different knowledge attributions, particularly so when using response deadlines. The response deadline manipulation used here demands a sequential procedure, otherwise participants would have ten possible response options per sequence, which would be too difficult when they are required to respond as quickly as possible (and which would also presuppose the definitions of all categories are remembered throughout). Nevertheless, it could be the case that if the sequence remains present during and past the response deadline, participants could make their grammar judgment based on unconscious structural knowledge before having time to consciously apply a rule and consequently select a rule or recollection attribution despite their grammaticality decision not being based on this strategy. Conversely, if the sequence is removed at the deadline, participants could have consciously applied a rule or recollective experience to the sequence which is subsequently forgotten and therefore would select an unconscious structural knowledge attribution. To account for these possibilities (of on-line vs. off-line knowledge attributions) two short deadline conditions were used: one where the grammar sequence disappeared at the deadline – sequence absent – and one where it remained for the grammaticality, attribution and confidence decisions – sequence present (see Section 7.2; see also Scott & Dienes, 2010b).

7. Method

7.1. Design and participants

Eighty-six new participants were recruited at the University of Sussex (ages ranged from 18 to 31 years) and were randomly assigned to one of the conditions: short deadline with sequence present, short deadline with sequence absent or no deadline. The same grammar cross-over design was used as in experiment 1.

7.2. Materials and procedure

EPrime 2.0 software was used to display stimuli and record responses. The same materials and training procedure were used as in experiment 1. After training, participants were informed about the existence of rules underlying the grammar sequences before a training block of trials commenced. The training block was necessary for participants to practice responding appropriately to the set deadline and to be familiarised with the three required responses to each test sequence. The practice block was the same as used in Mealor and Dienes (2012a) and consisted of 10 simple mathematics questions. Participants had to decide whether the sum was correct or incorrect (e.g.: 2 + 7 = 9; 50% of sums were correct). An initial fixation cross was displayed on the screen for 2500 ms before the sum appeared. When participants were required to respond, a tone (11 kHz, duration of 100 ms) sounded through a pair of headphones. Participants responded by pushing the 1 (yes – correct) or 0 (no – incorrect) keys. In order to eliminate anticipatory responses, a response could not be entered until the tone had sounded. After making their response, participants chose an attribution then entered their confidence rating in their grammaticality decision as per experiment 1 (they were informed these choices were more relevant for the testing trials and again were provided with a booklet of the definitions of the knowledge attributions and confidence which they were allowed to refer to during the non-speeded parts of the procedure). In the no deadline condition, the sum was displayed for 5000 ms to ensure a broad range of response times before the tone; these participants were informed they could not respond until after the tone but they could take as much time as they wished before making their decision. The sum remained on the screen until all three responses had been made. In the short deadline sequence present condition, the tone sounded after the sum had been displayed for 500 ms and participants were required to input their response as soon as they heard the tone. The sum remained on the screen during all three responses. In the short deadline sequence absent condition the sum disappeared when the tone sounded and did not appear for attribution or confidence input. If participants in the short deadline conditions took longer than 1000 ms to make their response, a message appeared on the screen reading "Please respond faster". If they took less than 1000 ms, the message would read "You're doing great". No time limits were set for attribution or confidence input.

After the training block had finished the testing block began. These followed the same format as the practice trials for all three conditions. In the no deadline condition the grammar sequence appeared on the screen for 5000 ms before the tone sounded. After participants made their grammaticality choice, the sequence remained on the screen for attribution and confidence input. The same procedure applied to the short deadline sequence present condition except the tone sounded after 500 ms when participants were required to respond. In the short deadline sequence absent condition, the grammar sequence disappeared after the tone at 500 ms and did not reappear for attribution or confidence input. After 60 trials (50% grammatical), the experiment was over.

8. Results

Intuition and familiarity responses were again pooled into an unconscious structural knowledge category and rules and recollection responses were pooled into a conscious structural knowledge category as per experiment 1. Note the degrees of freedom throughout: not all participants used all available response types and thus these participants could not be entered into analyses with knowledge type as a within-subject variable (confidence data were also unavailable for one participant).

Firstly the possibility of systematic differences between the short deadline conditions are considered before addressing the primary hypotheses outlined in Section 6, which are only concerned with responses made with conscious judgment knowledge. The effect of deadline on the proportion of different knowledge types will be analysed; and then the effect of deadline on accuracy, which are our main concerns. Guessing knowledge is then addressed and finally the effect on accuracy will be analysed according to effects on hits and false alarms for both experiments 1 and 2.

8.1. Short deadline conditions

Systematic differences acting on the proportion of response types or their accuracy (see Table 2) between the sequence present and sequence absent short deadline conditions were investigated. Independent samples *t*-tests revealed no significant differences between the percentages of unconscious to conscious structural knowledge responses, $ts < 1.53$, $ps > .131$. Secondly, a 2 × 2 (sequence status [absent vs. present] by structural knowledge type [unconscious vs. conscious]) mixed ANOVA was conducted on the proportion of correct responses ($N = 53$). The mean proportion of correct unconscious structural knowledge responses was .61 ($SE = .02$) compared to .72 ($SE = .03$) for conscious structural knowledge. This expected

Table 2
The percentage of responses and proportion of correct responses as a function of sequence status in the short deadline conditions and structural knowledge type. Standard errors appear in parentheses.

	Unconscious structural knowledge		Conscious structural knowledge	
	Present	Absent	Present	Absent
Responses	51% (4.38)	57% (3.90)	33% (4.89)	24% (3.01)
Accuracy	.60 (.04)	.62 (.03)	.73 (.04)	.72 (.04)

difference was significant, $F(1,51) = 18.65$, $p < .001$. There was no significant main effect of sequence status, or a sequence status × response type interaction, $Fs < 1$. Thus, there was no evidence of a systematic difference acting on accuracy between the sequence present and absent conditions under the short deadline. Therefore, these data were pooled into an overall short deadline condition for the main analyses.

8.2. Percentages of different knowledge types

Mean exposure time to the grammar sequence from onset until response under the short deadline was 1193 ms ($SE = 32$) and was 6983 ms ($SE = 191$) under no deadline (84% of responses were made within the short deadline constraint). Independent samples t-tests were conducted in order to assess whether the deadline had an impact on the percentage of response types (see Table 3). There was no significant effect of deadline on unconscious structural knowledge responses, $t(84) = 0.20$, $p = .844$, 95% CI [−10.22, 8.37], showing the proportion of this response type was similar between deadline conditions. The effect of deadline on the percentage of conscious structural knowledge responses was significant, $t(84) = 1.69$, $p = .047$ (one-tailed). The short deadline led to an increase in guess responses, $t(84) = 2.29$, $p = .013$ (one-tailed), showing a shift from rule-based responding to guessing.

8.3. Effect of deadline on accuracy

Table 4 reports the proportion of correct responses as a function of knowledge type and deadline. Independent samples t-tests were conducted on the proportion of correct responses, revealing a significant reduction in unconscious structural knowledge accuracy under the deadline, $t(87) = 2.08$, $p = .040$, whereas no detectible difference in accuracy was found for conscious structural knowledge, $t < 1$. Further, the reduction in accuracy caused by the deadline was greater for unconscious than conscious knowledge, $t(80) = 2.51$, $p = .014$.

However, mean confidence in conscious structural knowledge responses was 77% ($SE = 1.07$) and 68% ($SE = 0.81$) in unconscious structural knowledge responses. The difference was significant, $t(79) = 10.20$, $p < .001$. Therefore, an effect of deadline on knowledge type could be influenced by the relative difference in confidence between knowledge types. The difference in confidence between conscious and unconscious structural knowledge responses (henceforth 'C_{Diff}') was calculated ($M = 9.44$, $SE = 0.93$) and a t-test conducted in order to determine if there was an effect of deadline. No significant difference was found between the no ($M = 7.66$, $SE = 1.50$) and short ($M = 10.46$, $SE = 1.16$) deadline conditions, $t(78) = 1.46$, $p = .148$, 95% CI [−1.01, 6.60], therefore C_{Diff} was considered suitable to enter into the main analysis as a covariate. The difference in accuracy between unconscious ($M = .64$, $SE = .02$) and conscious structural knowledge ($M = .70$, $SE = .03$) was also calculated (henceforth 'A_{Diff}'). When A_{Diff} was regressed on C_{Diff} there was significant relation, $F(1,77) = 12.21$, $p = .001$, $\eta_p^2 = .14$. Importantly, the difference in A_{Diff} between deadline conditions remained significant with C_{Diff} as a covariate, $F(1,77) = 4.86$, $p = .031$.

There was a reduction in accuracy of 39% for unconscious structural knowledge due to the deadline manipulation (from 18% to 11% above baseline). The 95% confidence intervals for conscious structural knowledge allow us to rule out the same proportional change for this response type (a reduction of no more than 6% would be expected based on the lower bound of the 95% CI for conscious structural knowledge under the deadline). Accuracy was above chance for both response types under both short and no deadline conditions, $ts \geqslant 3.53$, $ps \leqslant .001$, thus both conscious and unconscious structural knowledge was expressed under both conditions (note the 95% confidence intervals in Table 4 do not cross the chance value of .50).

Table 3
The percentage of response types according to deadline. Standard errors appear in parentheses.

Structural knowledge type	No deadline	Short deadline
Guess	11% (1.96)	18% (1.98)
Unconscious	54% (3.16)	54% (2.92)
Conscious	36% (4.02)	28% (2.70)

Table 4
Proportion of correct responses as a function of deadline and structural knowledge type (95% confidence intervals appear in parentheses). Descriptive statistics are based on unadjusted means.

Structural knowledge	No deadline	Short deadline
Unconscious	.68 [.63, .73]	.61 [.57, .65]
Conscious	.68 [.58, .78]	.73 [.67, .79]

8.4. Effects of deadline on guessing knowledge

In the no deadline condition, the mean proportion of correct guess responses (those based on unconscious knowledge of both structure and judgment) was .51 (SE = .05, 95% CI, [.42, .61]), thus did not satisfy the guessing criterion of unconscious knowledge (the CIs are quite consistent with guessing knowledge) and was .45 (SE = .03, 95% CI, [.39, .51]) under the deadline (note that there was no detectible difference between deadline conditions, $t < 1.10$). This *prima facie* contradicts the results of experiment 1, but note that in only 22 participants gave a guess response under the no deadline condition compared to 42 available for analysis in experiment 1. A Bayes factor was calculated to determine whether this result reflected evidence for the null or data insensitivity, where values less than 1/3 indicate strong evidence for the null hypothesis; values over 3 indicate strong evidence for the alternative hypothesis and values around 1 indicate no substantial support either way (see Dienes, 2008b, 2011, for rationale). The difference between guess accuracy without deadline and baseline performance was .01 (SE of the difference = .05). In order to calculate a Bayes factor, a plausible effect size needs to be specified. A reasonable guessing knowledge accuracy estimate was calculated form similar studies using structural knowledge attributions after incidental learning conditions in AGL (Dienes & Scott, 2005; Mealor & Dienes, 2012b; Scott & Dienes, 2008, 2010b), giving an arithmetic mean of .56. Thus, guessing knowledge without a deadline in experiment 2 was modelled as a half normal, with the lower limit set at 0 (indicating baseline) and the SD set to .06, yielding a Bayes factor of 0.73, indicative of data insensitivity. However, under the deadline the proportion of performance was marginally worse than baseline, $t(54) = 1.75$, $p = .087$. This point is returned to in Section 9.

8.5. Experiments 1 and 2: effects of deadline on hits and false alarms

The accuracy results obtained in both experiments were supplemented with a signal detection analysis. See Table 5 for descriptive statistics. Hit rates (correctly endorsing grammatical sequences as grammatical) and false alarm rates (erroneously endorsing ungrammatical sequences as grammatical) were calculated along with d' separately for the response categories. The value of d' corresponds to the difference in the standardised distributions representing noise trials (ungrammatical sequences) and signal-plus-noise trials (grammatical sequences) in terms of sequence endorsement. As values of d' increase, participants show a greater ability to discriminate between grammatical and ungrammatical sequences (where a value of 0 indicates no reliable discrimination). Hit rates (HRs) and false alarm rates (FARs) with a value of 1 or 0 are problematic for calculating these measures, thus the following formulae were used (from Snodgrass & Corwin, 1988): $HR = (H + 0.5)/(H + M + 1)$ where H and M refer to the frequency of hits and misses (incorrectly rejecting a grammatical sequence) respectively; and $FAR = (F + 0.5)/(F + CR + 1)$ where F and CR refer to the frequency of false alarms and correct rejections (correctly rejecting a sequence as ungrammatical). This adjustment can be understood as having a Bayesian prior

Table 5
Hit rate (HR), false alarm rate (FAR), discrimination (d') and response criterion (C) for conscious and unconscious structural knowledge responses as a function of deadline condition. Standard errors appear in parentheses.

Structural knowledge		HR	FAR	d'	C
Experiment 1					
Conscious		.72 (.03)	.25 (.03)	1.54 (.14)	0.08 (.08)
Unconscious		.70 (.03)	.32 (.03)	1.18 (.14)	0.00 (.07)
Guess		.51 (.03)	.34 (.03)	0.33 (.12)	0.16 (.08)
Experiment 2					
Conscious	Deadline	.61 (.03)	.28 (.04)	1.02 (.15)	0.19 (.07)
	No deadline	.66 (.04)	.28 (.04)	1.26 (.23)	0.10 (.09)
Unconscious	Deadline	.64 (.02)	.42 (.03)	0.63 (.11)	−0.09 (.05)
	No deadline	.67 (.03)	.32 (.03)	1.06 (.14)	0.03 (.07)
Guess	Deadline	.41 (.03)	.50 (.03)	−0.25 (.11)	0.14 (.06)
	No deadline	.44 (.05)	.37 (.05)	0.30 (.16)	0.28 (.11)

Note: Values of C reflect response criterion where positive values indicate a conservative response bias and negative values indicate a liberal bias. There are necessarily fewer participants included in the discrimination statistics than the proportion of correct responses and HR/FAR as d' calculations are dependent on both endorsing and rejecting at least one test stimulus.

that d' equals zero, worth two observations. Specifically, the prior corresponds to having 95% confidence that d' (and beta) lies between ±3.

For experiment 1, the ANOVA on HR revealed a significant main effect of response type, $F(2,82) = 17.90$, $p < .001$. Bonferroni adjusted comparisons showed a significantly higher HR for both conscious and unconscious structural knowledge over guesses, $ps < .001$; and no significant difference between conscious and unconscious structural knowledge, $p = .463$. The ANOVA on FAR revealed a significant main effect of response type, $F(2,82) = 5.60$, $p = .005$. Bonferroni adjusted comparisons showed a significantly higher FAR associated with guesses than conscious structural knowledge, $p = .015$. The difference between unconscious structural knowledge and guesses did not quite reach significance, $p = .094$; nor did the conscious vs. unconscious structural knowledge comparison, $p = .440$. However, the differences in HR and FAR translated into a significant effect on d', $F(2,82) = 33.22$, $p < .001$. Bonferroni adjusted pairwise comparisons showed that conscious structural knowledge responses resulted in greater sensitivity to grammaticality than unconscious structural knowledge, $p = .022$, and guessing, $p < .001$. Unconscious structural knowledge responses also resulted in greater sensitivity than guesses, $p < .001$. The analysis presented here supports the analysis on the proportion of correct responses in experiment 1.

For experiment 2, responses made with conscious judgment knowledge were considered. As it was unclear whether a deadline would decrease hits or increase false alarms (or both), no *a priori* predications were made. Separate 2 (Structural knowledge type: unconscious vs. conscious) × 2 (short deadline vs. no deadline) mixed ANOVAs were conducted on HR and FAR respectively. No significant main effects or interactions were found to act on HR, $Fs < 1.13$. There was no significant main effect of deadline on FAR, $F < 1.45$. However, there was a significant main effect of response type, with unconscious structural knowledge associated with a greater FAR ($M = .37$, $SE = .02$) under the deadline compared to no deadline ($M = .28$, $SE = .03$), $F(1,80) = 14.71$, $p < .001$. This finding was qualified by a significant response type × knowledge type interaction, $F(1,80) = 5.21$, $p = .025$. The mean FAR of unconscious structural knowledge was .03 ($SE = .04$) higher than for conscious structural knowledge in the no deadline condition and was .14 ($SE = .03$) higher in the short deadline condition. Furthermore, considering unconscious structural knowledge responses separately, the short deadline significantly increased the FAR compared to no deadline, $t(84) = 2.16$, $p = .033$.

The effect of deadline on FAR for unconscious structural knowledge translated into a significant effect of deadline on d' for unconscious knowledge: no deadline resulted in significantly better discrimination between grammatical and ungrammatical sequences than the short deadline, $t(84) = 2.05$, $p = .043$ (note that d' of unconscious structural knowledge was significantly greater than zero under both deadline conditions, $ts > 6.23$, $ps < .001$). There was no detectable effect of deadline on d' for conscious structural knowledge, $t < 1$, (and d' for conscious structural knowledge was significantly greater than zero under both deadline conditions, $ts > 5.56$, $ps < .001$).

9. Discussion

The short response deadline reduced the *quality* of responses attributed to unconscious structural knowledge. There are two possible explanations for this effect. Firstly, it could be the case that without sufficient time, a conscious feeling of familiarity does not have time to settle when decisions are externally enforced. This feeling of familiarity therefore misrepresents lower order unconscious structural knowledge, in effect lowering the accuracy of decisions made in this manner (cf. Rosenthal, 2000). The second possibility is that if higher order representations (judgment knowledge) are integrated with first order familiarity (structural knowledge) via re-entrant loops then deadlines interfere with this integrative process, distorting the lower order knowledge leading to inaccuracy (cf. Kriegel, 2007). Crucially, accuracy was above chance for unconscious knowledge under the short deadline showing it is possible for familiarity-based unconscious knowledge to be elicited rapidly, as is predicted by dual process theory. However, without sufficient time for metacognitive judgment of that knowledge to complete, decisions are made at suboptimal levels, as suggested by higher order thought and cross-order integration theories and in support of the hypotheses. The reduction in accuracy of this knowledge type was mainly driven by an increase in false alarms (erroneously endorsing ungrammatical sequences as grammatical). As the percentage of trials attributed to unconscious structural knowledge was largely unaffected by deadline (54% in both cases) participants still experience a metacognitive feeling of familiarity but the reliability of that feeling is compromised without sufficient processing time (see also Glöckner & Witteman, 2010).

Secondly, the deadline reduced the *proportion* of overall conscious structural knowledge attributions and increased the likelihood of random selection responses, in support of dual process theory. Although the deadline did not affect the accuracy of conscious structural knowledge within experiment 2, the trend towards a greater proportion of overall random selection responses suggests that when conscious structural knowledge is not at maximal strength (or perhaps the known rules are too complex), people do not have time to apply it. The same effect was not found for unconscious structural knowledge responses; presumably because rule based responding in AGL is an all-or-nothing categorical process which is not true of using continuous familiarity signals to guide responses (Sun, 2002). When participants do not have the time to apply conscious structural knowledge they may feel as if they know nothing at all (and opt to guess; cf. the two-stage recollection hypothesis of Moscovitch, 2008). The reduced proportion of conscious structural knowledge attributions could also reflect differences in conscious decision strategies used by participants. Presumably, grammaticality decisions where a sequence could be classified on the basis of a relatively small amount of information (e.g.: the appearance or absence of a salient bigram remembered from training) would be made relatively rapidly due to the small amount of information required to satisfy the decision criterion of that participant compared to more complex rules (e.g.: evaluating a sequence on the basis of its global repetition structure where more elements in the sequence would require matching to the stored conscious structural knowledge) and the trials involving these more complex evaluations are the driving force behind the reduction in conscious structural knowledge responses. Related to this point, it is possible that for some trials under the deadline participants attempted to apply conscious structural knowledge rapidly, realised their judgment was incorrect then (mis)reported their decision strategy was a random selection (explaining the poor performance of guesses under the deadline in experiment 2). However, this 'demand characteristics' interpretation still supports the hypothesis that when structural knowledge is conscious it can take time to be applied; only after making their grammar decision did participants realise they were incorrect and misreported their attribution as random selection (i.e.: they became consciously aware of their accurate structural knowledge only after the deadline). In fact, guess responses under the deadline were marginally *poorer* than baseline. There is no *a priori* reason for this to be the case, and stands in stark contrast with results found using the no-loss gambling procedure. Thus, the favoured interpretation is the misreporting of knowledge as, when given sufficient processing time, a rule or recollection response would have been made else the performance of guessing knowledge would be no different from chance as a minimum. The one-step procedure may therefore be the more sensitive technique to elicit veridical knowledge when the judgment is unconscious (the conscious–unconscious judgment knowledge distinction motivates no-loss gambling as a methodology) where the two-step procedure allows for more opportunities to misreport knowledge states, but is sensitive to the conscious–unconscious structural knowledge division. A more direct investigation of how response deadlines impact on one- and two-step procedures and how this affects scale sensitivity is a matter for future investigation (see Wierzchoń, Asanowicz, Paulewicz, & Cleeremans, 2012, for recent work on response scale sensitivity and confidence in AGL; see also Gardiner et al., 2002 for a discussion of the factors affecting guessing in recognition memory studies).

The reduction in performance of unconscious structural knowledge compared to conscious structural knowledge was not mediated by the relative difference in confidence between these knowledge types, further suggesting a qualitative difference between these knowledge types. The dissociations found in experiment 2 strengthen the conclusions of experiment 1, specifically that the phenomenological differences captured in conscious and unconscious structural knowledge attributions reflect qualitatively distinct states, which have some degree of independence from the levels of confidence associated with those states in terms of the amount of time such knowledge takes to be applied.

10. General discussion

The current experiments replicate and extend the findings of Mealor and Dienes (2012a). In self-paced AGL tasks, responses based on both conscious structural and judgment are made most rapidly, followed by responses based on unconscious structural knowledge accompanied with conscious judgment and those made without any metacognitive preference for grammaticality are made most slowly. Importantly, it was also found that the different types of structural knowledge attribution showed a qualitative difference in terms of RTs once accuracy and confidence were partialled out. This finding has good face validity: it would be possible to have high confidence in a strong feeling of familiarity (as in the "butcher on the bus" phenomenon; Mandler, 1980; see also Wixted & Mickes, 2010) or have low confidence in weakly held or overly-complex consciously recognised rules (Dienes, Scott, & Seth, 2010). Experiment 2 showed dissociations between structural knowledge types in terms of how response deadlines affect such knowledge. Firstly, when responses were based on intuition or familiarity, the response deadline reduced the quality of those decisions, but not the overall proportion of these response types (54% of responses were attributed to intuition or familiarity under both short vs. no deadline conditions and in the self-paced responding of experiment 1). The main driving force behind the reduction in accuracy of this knowledge type was an increase in false alarms (cf. Johansson, 2009). This finding has similarities to those of Higham, Pritchard, and Vokey (2000) who found an increase in the acceptance of to-be-rejected sequences as grammatical under a response deadline. Here we extend the account to responses reported with subjective measures of awareness (there was an increase in false alarms associated with intuition and familiarity based responses under the deadline but not with recollection or rule-based responses; furthermore, the deadline increased the false alarm rate of unconscious structural knowledge relative to conscious structural knowledge). Response deadlines are thought to encourage non-analytic processing of the stimuli where the item is evaluated as a whole rather than its constituent parts (analytic processing). It seems reasonable that an increase in false alarms may be a result of such non-analytic processing where simply surface elements are evaluated and not the relations between them which leads to an increase in accepting ungrammatical sequences as grammatical (see also Johansson, 2009; Scott & Dienes, 2010b). See also the proposal of 'matching intuition' (Glöckner & Witteman, 2010) which assumes intuitively based judgments (here, unconscious structural knowledge accompanied by conscious judgment knowledge) suffer time–costs with an increasing number of learning experiences (i.e.: exemplars encountered during training would be the incidental learning experiences in AGL).

The opposite pattern was found for responses based on rules and recollection where knowledge goes beyond the overall familiarity of the sequence. The quality of those decisions was retained but the number of responses was reduced in favour of random selection (the proportion of conscious structural knowledge attributions in the no deadline condition and the self-paced responding of experiment 1 were comparable at 36% and 34% respectively, whereas in the short deadline condition this was reduced to 28% of responses). These findings corroborate both dual process theory and higher order thought and/or cross-order integration theories and suggest a qualitative difference between responses based on conscious and unconscious structural knowledge. That structural knowledge attributions behave in ways in line with hypotheses based on both higher-order thought theories (which motivated their initial introduction in Dienes & Scott, 2005) and dual process theory (a quite separate theory) further validates their use as a measurement tool.

The difference between the proportion of correct responses for conscious structural knowledge in experiment 1 (.80) and the no deadline condition of experiment 2 (.68) seems surprising. However, this is actually a virtue of the manipulation used in experiment 2: the no deadline condition resulted in the same accuracy level for conscious and unconscious structural knowledge, which satisfies the recommendations of Lau and Passingham (2006) in that there was no confound in first order performance (see also Lau, 2008). Thus, the method and analysis employed in experiment 2 is the most controlled way of assessing the effect of the response deadline upon types of structural knowledge. Extending this argument, equal accuracy levels for conscious and unconscious structural knowledge speak against a simple notion of a graded quality of representation (i.e. placing unconscious and conscious structural knowledge on a continuum) when a further deadline manipulation can dissociate them (see Seth, Dienes, Cleeremans, Overgaard, & Pessoa, 2008). Conscious and unconscious structural knowledge attributions do appear to capture qualitatively distinct states, at least in terms of the time taken to make decisions based on those processes. Returning to the difference in accuracy for conscious structural knowledge between experiment 1 and the no deadline condition of experiment 2[1], the difference between grammar sequence onset and response for a conscious structural knowledge response in experiment 1 and for a response under no deadline in experiment 2 was approximately 3 s. This raises the possibility that too much conscious deliberation in AGL harms conscious structural knowledge, possibly to a greater extent than unconscious structural knowledge. Reduced performance following and arbitrarily enforced period of rumination is a well verified effect in other domains (e.g. Wilson & Schooler, 1991; Waroquier, Marchiori, Klein, & Cleeremans, 2009, 2010), and such results are often interpreted under verbal overshadowing (Chin & Schooler, 2008; Schooler & Engstler-Schooler, 1990) or unconscious thought (Dijksterhuis, 2004; Dijksterhuis & Nordgren, 2006) theoretical frameworks (see also Payne, Samper, Bettman, & Luce, 2009 for the advantages of self-paced conscious thought over an enforced period of thought). Although this is a preliminary result, further research could more thoroughly explore the role of rumination on implicit learning on a per-trial basis (see also Mealor & Dienes, 2012b, for work on different modes of thought between training and testing in AGL).

With respect to the findings of Mealor and Dienes (2012a), we can now state that when both structural and judgment knowledge are unconscious, the quality of decisions based on these knowledge types is as good as it will ever be in roughly 500 ms (for the materials used). However, in self-paced tests, this response type takes longest to be expressed as people await a metacognitive feeling of judgment; if this feeling is not forthcoming then they opt to guess. Nonetheless, the process of conscious judgment at least begins in the same time frame when participants have metaknowledge about the sequence. When structural knowledge is unconscious, but is accompanied with conscious judgment knowledge, decisions can be made in roughly 1000 ms, but extra time is required for judgment knowledge to be optimally reliable, likely due to the time costs involved in evaluating continuous familiarity signals. Finally, when both types of knowledge are conscious, decisions appear binary in nature but people may have trouble applying this all-or-nothing response before 1000 ms (and indeed may realise errors in their classification after this time). These findings are broadly in line with those in the recognition memory literature. In a review paper, Yonelinas (2002) states that familiarity responses are impaired before 750 ms and are largely optimal in around 1000 ms, whereas recollection requires additional retrieval time. We extend this account to AGL, where test stimuli are evaluated on the basis of similarity to exemplars, rather than recollecting the actual previous presentation and presumably this is why the RTs are slightly longer than those reported in R/K studies.

Notably, the results presented here are *prima facie* at odds with those of Turner and Fischler's (1993) AGL study where participants were either trained in a memorise condition (similar to the incidental learning used in the current experiments which is thought to minimise explicit learning of the grammar) or instructed them to search for rules (thought to maximise explicit learning). They found that a response deadline in the test phase had a larger impact on the accuracy of participants in the rule-search condition, that is under conditions more likely to give rise to conscious structural knowledge. However, there is no reason to believe memorise vs. rule search conditions are process pure in that both elicit conscious and unconscious structural knowledge (e.g.: Dienes & Scott, 2005) and the efficacy of rule search instructions in improving the quality of knowledge may be dependent on the difficulty of the grammar in question (Reber, 1976). Thus, rule search instructions may be more likely to lead to a shift in processing style rather than substantially affecting accuracy depending on the experimental materials. Future research could more systematically investigate the impact of different AGL training conditions on different knowledge types and their robustness vs. vulnerability to time pressure (see also Domangue, Mathews, Sun, Roussel, & Guidry, 2004; Sallas, Mathews, Lane, & Sun, 2007).

In summary, this paper shows that the 'natural' time course of knowledge in AGL is expressed in order of its conscious status: firstly conscious structural knowledge (rule or recollection based responding), then unconscious structural knowledge accompanied by conscious judgment (feelings of intuition or familiarity) then unconscious structural and judgment knowledge (self-reported random responding, i.e.: guessing). Self-paced tests reveal the time courses of these knowledge types are not reducible simply to differing levels of confidence associated with such knowledge. Response deadlines show intuitive or familiarity based responding benefits from additional evaluation time in order to reach maximum quality whereas, in circumstances where it can be applied, rule-based responding is well formed in around 1000 ms, even when

[1] An independent samples t-test between the accuracy of conscious structural knowledge in experiment 1 and the no deadline condition of experiment 2 indeed reveals a significant difference, $t(40.31) = 2.19$, $p = .034$ (degrees of freedom corrected for a homogeneity of variance violation). The same is not true of unconscious structural knowledge, $t(81) = 1.33$, $p = .188$; and, furthermore, the interaction reaches significance, $F(1, 76) = 4.14$, $p = .039$.

differences in relative confidence levels are accounted for (and extending this period beyond a self-defined optimal amount of thought may detract from its quality). However, when conscious structural knowledge is not strong enough, or is too complex, people have trouble applying it rapidly and opt to report their decision as a random selection. The differences in the time courses of these knowledge types and how deadline pressure affects such knowledge suggests a qualitative distinction between conscious and unconscious structural knowledge.

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