Consciousness and Cognition 21 (2012) 228–237

Contents lists available at SciVerse ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

No-loss gambling shows the speed of the unconscious

Andy Mealor *, Zoltan Dienes

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

ARTICLE INFO

Article history:
Received 19 May 2011
Available online 26 December 2011

Keywords:
Unconscious knowledge
Subjective measures
Wagering
No-loss gambling
Artificial grammar learning
Implicit learning
Dual process

ABSTRACT

This paper investigates the time it takes unconscious vs. conscious knowledge to form by using an improved "no-loss gambling" method to measure awareness of knowing. Subjects could either bet on a transparently random process or on their grammaticality judgment in an artificial grammar learning task. A conflict in the literature is resolved concerning whether unconscious rather than conscious knowledge is especially fast or slow to form. When guessing (betting on a random process), accuracy was above chance and RTs were longer than when feeling confident (betting on the grammaticality decision). In a second experiment, short response deadlines only interfered with the quality of confident decisions (betting on grammaticality). When people are unaware of their knowledge, externally enforced decisions can be made rapidly with little decline in quality; but if given ample time, they await a metacognitive process to complete. The dissociation validates no-loss gambling as a measure of conscious awareness.

© 2011 Elsevier Inc. All rights reserved.

1. Introduction

How can we tell if someone is aware of their knowledge? Artificial grammar learning (AGL; Reber, 1967) is a particularly useful methodology to address this question as it demonstrably elicits both conscious and unconscious knowledge according to subjective measures of awareness (e.g. Dienes, 2008; 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 an 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 rules, patterns of connection weights, chunks, or whole items taken as examples of the structure). During testing, participants classify further novel sequences in terms of their grammaticality (whether they conform to or violate the studied rules). Here, judgment knowledge is the (conscious or unconscious) knowledge constituted by such a judgment (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 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. Fig. 1 depicts the relationship between the conscious status of these knowledge types and the associated phenomenology (see also Scott & Dienes, 2010a, for a model of how structural and judgment knowledge develop in AGL; and Scott & Dienes, 2008; Pasquali, Timmermans, & Cleeremans, 2010, for models of how judgment knowledge may become conscious).

* 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. Mealor).

1053-8100/$ - see front matter © 2011 Elsevier Inc. All rights reserved.
doi:10.1016/j.concog.2011.12.001

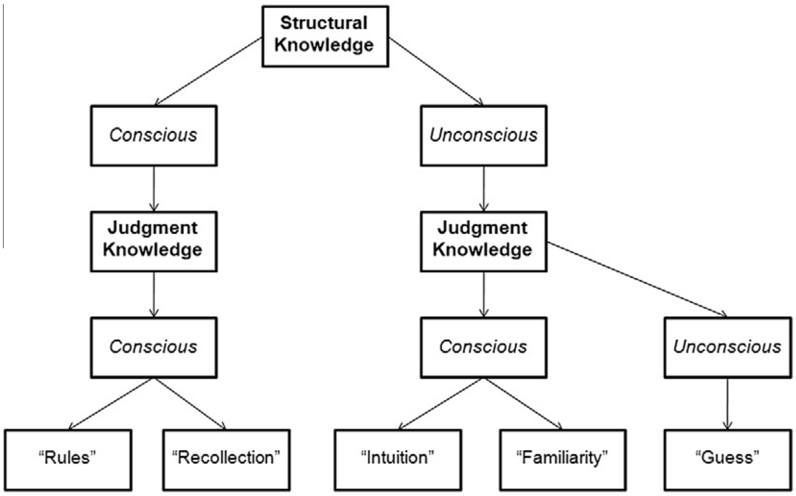

Fig. 1. The relationship between the conscious status of structural and judgment knowledge and the associated phenomenology. The bottom row depicts self-reported structural knowledge attributions (see Dienes & Scott, 2005; Scott & Dienes, 2008).

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) and structural knowledge attributions (Dienes & Scott, 2005; Scott & Dienes, 2008, 2010a, 2010b, 2010c; Wan, Dienes, & Fu, 2008; see also Chen et al., 2011; Guo et al., 2011; Rebuschat & Williams, 2009). Recently, wagering has been used to assess conscious awareness. In their AGL study, Persaud, McLeod, and Cowey (2007) asked participants to make high or low wagers using real or imaginary money after making a grammaticality decision. When correct, the wager was added to their total; when incorrect it was deducted. The procedure was presumed to motivate participants to make consistently high wagers whenever they felt more confident than a mere guess in order to maximise financial gain (Koch & Preuschoff, 2007). A tendency to wager high on accurate decisions would then provide an index of subjective awareness which is particularly useful for researchers shy of overestimating unconscious knowledge, a potential pitfall of using verbal reports (Berry & Dienes, 1993). Persaud et al. found that despite a high level of overall performance (81% accuracy) participants made high wagers at a lower than optimal level. This was taken as evidence that participants were unaware of their knowledge (contrast Clifford, Arabzadeh, & Harris, 2008).

However, this post-decision wagering procedure has been criticised due to the potential problem of risk (loss) aversion (Kahneman & Tversky, 1979). For the risk averse participant, losing a certain amount of money is more salient than gaining the same amount. This may encourage consistently low wagers to minimise loss when they do have some awareness of knowledge. In effect, this increases the rate of measured unconscious knowledge as operationalised by Persaud et al. (2007). Conversely, participants showing little risk aversion may be willing to wager large amounts on what, to them, seems like a random process. Thus, wagering without sensitivity to the risk aversion of the individual distorts conclusions drawn about the amount of conscious or unconscious knowledge expressed (Schurger & Sher, 2008). Indeed, Fleming and Dolan (2010) found that economic factors in post-decision wagering systematically influenced measures of perceptual sensitivity. Altering the wager size affected the proportion of low to high wagers which would lead one to change conclusions drawn about low or high levels of awareness. Furthermore, Dienes and Seth (2010) compared a binary verbal confidence scale ('guess' vs. 'sure') against wagering in an AGL task while measuring risk aversion. They found a greater willingness to indicate confidence in responses using the verbal scale and that risk aversion significantly correlated with the amount of conscious knowledge as measured by wagering, but not as measured by verbal confidence.

In a second experiment, Dienes and Seth (2010) introduced a new methodology to indicate the presence of unconscious knowledge in AGL: No-loss gambling. During the test phase, participants indicated their confidence in each grammaticality decision by either betting on the grammaticality decision (in order to win one sweet if correct) or on a transparently random process. If they chose the latter, they shuffled and then picked one of two face-down cards, one of which had 'SWEET' printed on the invisible side, the other had 'NO SWEET'. Therefore choosing to bet on the cards meant there was a 50:50 chance the participant would add to their winnings. If one chooses to bet on the random process, rather than on the grammaticality decision, clearly no conscious preference for grammaticality or ungrammaticality is shown. This methodology bypasses the potential confound of risk aversion as participants never have the opportunity to lose their winnings but motivation to perform is maintained to maximise gains. When betting on the cards, participants still displayed above chance classification accuracy, satisfying the guessing criterion of unconscious knowledge (Dienes et al., 1995).

In using verbal reports, participants may have their own idiosyncratic definition of 'guess' (Gardiner, Ramponi, & Richardson-Klavehn, 1998). In everyday language, 'guess' can refer to a range of feelings of confidence. In classifying a test sequence some participants might say 'guess' when it felt as if they knew literally nothing relevant (the definition of 'guess' we are interested in – the absence of confidence) whereas others may take 'guess' to mean merely 'low confidence'. Merely 'low' confidence decisions can involve some awareness of knowing. However, betting on a random process shows a lack of conscious judgment: they are unaware of having any relevant structural knowledge. This is a literal guess as even if confidence in a decision was low, but not absent, it would still be worth betting on the grammar judgment to maximise reward rather than opting for the 50:50 gamble. Furthermore, this plausibly eliminates the problem of bias shown by any participant who says they are guessing but thinks they are not (Dienes, 2008). In other words, no-loss gambling robustly distinguishes conscious from unconscious judgment knowledge (see Fig. 1: No-loss gambling prima facie separates the guess response based on unconscious judgment knowledge from all other response types made with some degree of conscious judgment knowledge).

This paper aims to improve on the methodology of no-loss gambling. In the original study by Dienes and Seth (2010), participants attributed their knowledge (by betting on the grammar decision or on the cards) after the grammar judgment was made. It is possible that awareness of judgment knowledge can be relatively transient. This conscious knowledge could be forgotten, or could degrade, between the two decisions leading one to bet on the cards despite having had conscious judgment knowledge. In effect this would increase the amount of unconscious knowledge as measured by betting on the cards. To address this problem it is simply a matter of ensuring both grammaticality classification and decision strategy are reported simultaneously while the test sequence is available to account for this possibility (cf Tunney & Shanks, 2003, with verbal confidence ratings).

Further, no method can a priori prove itself from the arm chair just because it has good face validity. More broadly, the utility of the no-loss gambling methodology can only be verified if the results it yields are in line with theoretically motivated hypotheses (Dienes, 2004, 2008). Thus, a further aim of the paper is to demonstrate the utility of the method – by exploring a 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). This view is supported by Hintzman and Caulton (1997), who found shorter response times for item recognition than modality judgments requiring conscious recollection of a previous learning episode. Furthermore, Boldini, Russo, and Avons (2004) found that modality matches between learning and test (presumed to influence familiarity) under a strict deadline increased recognition compared to modality mismatches whereas under longer deadlines deep processing enhanced recognition compared to shallow processing (presumed to influence recollection). Such theories relate to AGL in that unconscious structural knowledge can express itself through familiarity and conscious structural knowledge can express itself through recollection. Consistently, in the context of AGL, Turner and Fischler (1993) found strict response deadlines had a greater impact on classification accuracy when participants had been instructed to search for grammar rules during training (thought to maximise explicit learning) compared to those who simply memorised training sequences (thought to minimise explicit learning).

However, studies using the remember-know methodology (R/K; Tulving, 1985) have provided contradictory evidence, finding that in self-paced tests, fully recollective responses are made more rapidly than those based on just familiarity (the R/K method involves subjects reporting on the phenomenology associated with recognition responses, with remember – R – responses indicating recollection, know – K – responses indicating just a feeling of familiarity, and guess – G – indicating no feeling of memory at all). For example, Dewhurst, Holmes, Brandt, and Dean (2006) found that after participants had studied word lists, subsequent 'remember' responses to test stimuli were made most rapidly, followed by 'know' responses (indicating familiarity without conscious recollection) then 'guess' responses (see also Dewhurst & Conway, 1994; Dewhurst, Hitch, & Barry, 1998; Henson, Digg, Shallice, Josephs, & Dolan, 1999; Konstantinou & Gardiner, 2005). Dewhurst et al. (2006) concluded that RTs reflect the time taken to make a decision based on the recollection or familiarity process and RTs may not reflect the actual retrieval process *per se* (i.e. the time differences in responses may be based on the information afforded to *metaknowledge* by R, K or G processes). The R/K method as applied to memory presumably taps similar processes as recollection and familiarity in AGL, though the interpretation is not exactly the same. R and K both involve conscious knowledge that an item was presented before, but familiarity- or rule-based -responses in AGL are not a commitment to an item having been presented before, but to the item being grammatical or ungrammatical. R responses are analogous with rule or recollection responses in AGL; both are dependent on consciously recognising that the item, or parts of the sequence, had been presented previously. K responses reflect a feeling, without conscious recollection, that the item had been presented previously and similarly in AGL familiarity responses reflect feelings of oldness of parts or aspects of a stimulus, without consciously recognising the parts of the sequence leading to that conclusion. However, in the current experiments the focus is on guess responses. A 'guess' response in memory occurs in the absence of conscious judgement of whether the stimulus had appeared in training, and in AGL reflects the absence of conscious judgment of whether the sequence follows the grammatical structure from training (see Tunney, 2007, for implementation of the R/K methodology in an AGL task).

Wixted and Mickes (2010) argue that guess responses are made in R/K studies when the memory strength of a particular test item falls on the old/new decision criterion, in a similar manner to guess responses in AGL where the subjective familiarity of a particular test sequence is close to the subjective mean value acquired over the course of the experiment (Scott & Dienes, 2008). Gardiner, Ramponi, and Richardson-Klavehn (2002) concluded from a meta-analysis that the performance of guess responses in R/K studies is typically at chance levels. This means that longer RTs for guess responses could sometimes reflect a lack of knowledge. This is not true of AGL studies where the guessing criterion is often satisfied (e.g.: Dienes &

Altmann, 1997; Dienes & Scott, 2005; Dienes et al., 1995; Scott & Dienes, 2010b, 2010c; Tunney & Shanks, 2003), making it an ideal paradigm to investigate the time-course of how knowledge is expressed without conscious awareness of that knowledge. Thus, the primary aim of this paper is to validate the no-loss gambling method by showing it distinguishes responses made with confidence and those made without confidence, by testing the apparent contradiction between hypothesised rapid unconscious responses and the results of standard R/K studies in accordance with dual process theory.

2. Experiment 1

Experiment 1 aimed to replicate the findings of Dienes and Seth (2010) with an amended no-loss gambling methodology to ensure grammaticality classification and knowledge attribution were made simultaneously (cf Tunney & Shanks, 2003, for verbal confidence). Thus there was no possibility of a conscious mental state degrading between the grammaticality decision and indicating confidence. Above chance accuracy for gamble responses would thus satisfy the guessing criterion of unconscious knowledge. In R/K studies, RTs to 'guess' responses are longer than 'remember' or 'know' responses (Dewhurst et al., 2006). Furthermore, guesses are, by definition, made in the absence of confidence and confidence is inversely related to RT (Petrusic & Baranski, 2003, 2009). As such, RTs for bets on a random process should be longer than those for bets on the grammaticality decision.

3. Methods

3.1. Design and participants

Twenty-eight participants were recruited at the University of Sussex (79% female). Age range was 18–42 years ($M = 23.31$; $SD = 6.23$). Remuneration was either £3 or course credits. The two-grammar cross over design of Dienes and Altmann (1997) was used. Approximately half of the participants were trained on grammar A with ungrammatical sequences in the test phase taken from 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). Sequence length was between five and nine characters. The training lists were comprised of 15 training sequences from each 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. EPrime 2.0 software was used to display the stimuli and record responses. A fixed counterbalanced order was used in training and testing.

3.3. Procedure

Participants were tested individually at a computer and half viewed their list in reverse. During the training phase, the sequences appeared in the centre of the computer monitor (font Arial, point size 66) for 5000 ms before the screen went blank for 5000 ms. During this time the participant was required to write the sequence they had just seen on a piece of paper before the next sequence appeared. This procedure continued for all 45 sequences.

The participants were then informed that the sequences they had been reproducing obeyed a set of complex rules and they would be classifying further sequences in terms of their grammaticality. They were also informed about the response options. They were informed that if they had any confidence in their response, they would gain by betting on it: if they were correct they would win one sweet. If they had no confidence in their response they could bet on a 50:50 gamble instead for a chance to win one sweet. During the test phase, a fixation cross appeared on the screen for 2000 ms before the test string. Four options were available for each test sequence, corresponding to four number keys at the top of the keyboard. The options were as follows: 1. The sequence is grammatical and I will bet on this decision; 4. The sequence is NOT grammatical and I will bet on this decision; 7. The sequence is grammatical and I will bet on a 50:50 random process; 0. The sequence is NOT grammatical and I'll bet on a 50:50 random process. Thus, keys 1 and 4 indicated a "confident to some degree" response; 7 and 0 indicated a "guess" response. If participants chose to bet on their grammaticality decision, the fixation cross appeared before the next sequence was presented. If the participant was correct, one sweet was added to their total winnings (note that no feedback about accuracy was provided). If participants chose to bet on the 50:50 random process a message box appeared. There was a 50% chance the box would read 'You win' or 'You lose'. If the participant won, one sweet was added to their total winnings. At the end of the experiment, participants received their winnings (their choice of Smarties or Jelly Tots).

4. Results

All *t*-tests in both experiments are reported with two-tailed significance. One participant was excluded from the analyses for never choosing the 50:50 random process response. Bets on grammaticality decisions for the sake of brevity will henceforth be referred to as "confident" responses. This does not imply a high level of confidence, merely that participants had more confidence in these responses than betting on the random process (henceforth referred to as "guess" responses). Confident responses accounted for 58% of overall responses (SE = 4.07) and guesses accounted for 42% (SE = 4.07). The difference was marginally significant, $t(26) = 1.94$, $p = .063$, Cohen's $d = 0.75$. The proportion of correct responses when confident was .73 (SE = .04), significantly higher than the chance value of .50, $t(26) = 6.07$, $p < .001$ Cohen's $d = 1.57$. The proportion of correct responses when guessing was .60 (SE = .03), also significantly higher than chance, $t(26) = 3.42$, $p = .002$, Cohen's $d = 0.93$, indicating unconscious knowledge by the "guessing criterion" of Dienes et al. (1995). The accuracy of responses with confidence was significantly higher than when guessing, $t(26) = 3.70$, $p = .001$, Cohen's $d = 0.65$, indicating some conscious judgment knowledge according to the "zero correlation criterion" of Dienes et al. (1995).

RTs based on both confident and guess responses were not detectably different from being normally distributed, as shown by Kolmogorov–Smirnov tests, $Ds \leqslant .153$, $ps \geqslant .106$. Mean RT of confident responses was 4954 ms (SE = 348) and mean RT of guess responses was 5780 ms (SE = 403). The difference was significant, $t(26) = 2.20$, $p = .037$, Cohen's $d = 0.42$. Multiple regression analyses were conducted which conformed to Lorch and Myers' (1990) individual equation method. Response type was used to predict RT while controlling for any effect of accuracy. Accuracy was not a significant predictor of RT, $\beta = -.03$ (SE = .03), $t(26) = -1.20$, $p = .243$. Response type was a significant predictor of RT, $\beta = .12$ (SE = .05), $t(26) = 2.62$, $p = .014$, confirming that guess responses were generally more time consuming than confident responses.

5. Discussion

The findings of Dienes and Seth (2010) were replicated. Participants showed significantly above chance accuracy when betting on a random process, satisfying the guessing criterion of unconscious knowledge (Dienes et al., 1995). Furthermore, participants were willing to bet on a random process when grammaticality classification and decision strategy were made concurrently. This eliminated the possibility that a transient conscious judgment could degrade between sequence classification and reporting the decision strategy. Indeed the percentage of such "guess" responses in this experiment (42%) was higher than in the original study (28%). Unsurprisingly, responses based on betting on grammaticality ("confident" responses), indicating conscious judgment knowledge, resulted in higher accuracy than responses based on betting on a random process ("guess" responses). Guess responses (hence, based on unconscious structural and judgment knowledge) were made more slowly than sure responses. Regression analyses confirmed guess responses took longer when any influence of accuracy was accounted for. Thus, when judgment knowledge is unconscious, knowledge of structure takes longer to be expressed than when judgment knowledge is conscious.

6. Experiment 2

Experiment 1 showed that responses made with conscious judgment knowledge are made more rapidly than when judgment knowledge is unconscious. However, dual-process theories suggest that unconscious responses are made more rapidly (Yonelinas, 2002). How do we solve this contradiction? Dewhurst et al. (2006) suggest that RTs to R or K judgments in the R/K paradigm do not reflect the time course of those processes *per se*, but rather the time taken to make decisions based on the information afforded by those responses to metaknowledge. Thus, it could be the case that the output of unconscious structural knowledge itself is a rapid process but without conscious judgment of that output, it takes time to be expressed. Following from this, if both structural and judgment knowledge are unconscious no matter how much time is given to classify a stimulus, a conscious feeling of accurate judgment (an intuitive feeling of 'correctness' or familiarity) will never form. This is shown by willingness to bet on random processes with above chance accuracy on grammaticality decisions in self-paced tests. Additionally, Dienes and Scott (2005) failed to find evidence that guess responses would become associated with conscious judgment knowledge over trials. Thus, it could be the case that participants await conscious judgment knowledge and only bet on a random process when a metacognitive feeling of having reached a clear resolution is not forthcoming, resulting in longer RTs for this response type. Therefore a strict response deadline would not interfere with the quality of responses associated with betting on a random process as the final judgment is not consciously available and cannot optimise the decision. Conversely, if judgment knowledge itself takes time to be utilised, a response deadline should interrupt this process, resulting in reduced accuracy via sub-optimal decision making. Experiment 2 will distinguish these possibilities. Additionally, by combining the grammaticality and attributions together as a single response in experiment 1, it could be the case that it is the metacognitive decision (i.e. deciding on a response strategy) that takes time to be expressed rather than the grammaticality judgment. Thus, experiment 2 will also explore which of these decisions was the driving force behind the RT differences in experiment 1.

7. Methods

7.1. Design and participants

Twenty eight undergraduates from the University of Sussex participated in exchange for course credit (82% female). Age ranged from 18 to 36 years (M = 20.00; SD = 5.15). None had participated in experiment 1. The same grammar cross-over design was used as in experiment 1. The independent variables of interest were response deadline (short vs. none) and response type (guess vs. confident).

7.2. Materials and procedure

EPrime 2.0 software was used to display stimuli and record responses. The same training procedure was used as in experiment 1. After training, participants were informed about the existence of rules underlying the grammar sequences before a practice block of trials commenced. This block was necessary for participants to practice responding appropriately to the set deadline and to be familiarised with the available response options. The practice block followed a similar format to those used by Johansson (2009) and Turner and Fischler (1993). This block consisted of 10 simple mathematics questions and the participants had to decide whether the sum was correct or incorrect (e.g.: 2 + 7 = 9; 50% of sums were correct). They were instructed to rest their fingers on the 1, 4, 7 and 0 response keys at the top of the keyboard between trials. 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 concurrently with a backward mask of ampersands. In order to eliminate anticipatory responses, participants could not respond to the sum until the tone had sounded. Participants input their response by pushing the same response keys as in experiment 1. Yes – the sum was correct and I'll bet on this decision; 4. No – the sum was not correct and I'll be on this decision; 7. Yes – the sum was correct and I'll bet on a 50:50 random process or 0. No – the sum was not correct and I'll bet on a 50:50 random process. They were informed that these options would be more relevant for the testing trials. In the no deadline condition, the sum was displayed for 5000 ms before the tone and backward mask; 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 5000 ms display time was used to ensure a broad range of processing time compared to the short deadline condition. In the short deadline condition, the tone sounded and backward mask appeared after the sum had been displayed for 500 ms and participants were required to input their response as soon as they heard the tone. If participants in the short deadline condition took longer than 750 ms to make their response, a message appeared on the screen reading ''Please respond faster''. If they took less than 750 ms, the message would read ''You're doing great''.

After the practice block had finished the testing trials began. These followed the same format as the practice trials for both conditions. The same testing sequences, instructions for classifying sequences, and response key definitions were used as in experiment 1. In the no deadline condition, sequences were displayed for 5000 ms before the tone and backward mask. In the short deadline condition, the sequence was displayed for 500 ms. Again, participants received their winnings at the end of the experiment.

8. Results

One participant from the no deadline condition misunderstood the instructions and was omitted from the analyses, leaving 12 participants in the no deadline condition and 15 in the short deadline condition. Mean RT under the short deadline after the sequence had disappeared was 641 ms (*SE* = 73) whereas after no deadline it was 1330 ms (*SE* = 200).

Guesses accounted for 42% (*SE* = 3.60) of responses and confident responses accounted for 58% (*SE* = 3.60). Under the no deadline, guesses accounted for 45% (*SE* = 5.42) of responses and 39% (*SE* = 4.77) under the short deadline. The difference was not significant, $t(25) = 0.90$, $p = .376$, Cohen's $d = 0.35$, 95% CI [−8.34, 21.34]. There was no evidence that participants systematically changed their decision strategy according to deadline.

Fig. 2 shows the proportion correct for the different conditions. A 2 × 2 (Response [guess vs. confident] by Deadline [short vs. none]) mixed ANOVA was conducted on the proportion of correct responses ($N = 27$). There was a significant main effect of response type, $F(1,25) = 11.51$, $p = .002$, $\eta_p^2 = .32$. Confident decisions yielded higher accuracy ($M = .70$, $SE = .03$) than guess responses ($M = .60$, $SE = .03$). There was a significant main effect of deadline, $F(1,25) = 8.47$, $p = .007$, $\eta_p^2 = .25$. No deadline resulted in higher accuracy ($M = .71$, $SE = .03$) than the short deadline ($M = .59$, $SE = .03$). The important finding was a deadline x response type interaction, $F(1,23) = 8.84$, $p = .006$, $\eta_p^2 = .26$ (see Fig. 2). The accuracy of confident decisions was significantly reduced under the short deadline ($M = .60$, $SE = .03$) compared to no deadline ($M = .81$, $SE = .01$), $t(25) = 4.27$, $p < .001$, Cohen's $d = 1.16$. The same pattern was not found for guess responses. Accuracy under the short deadline ($M = .58$, $SE = .03$) was similar to that as under no deadline ($M = .61$, $SE = .04$), $t(25) = 0.55$, $p = .590$, 95% CI [−.08, .14], Cohen's $d = 0.21$. Critically, accuracy was significantly above chance for both response types under both deadline conditions, $ts \geqslant 2.23$, $ps \leqslant .042$ (note the 95% confidence intervals on Fig. 2 do not cross the line representing chance performance). The short deadline did not detectably interfere with the quality of guess responses. When knowledge of both structure and judgment was unconscious, decisions could be made rapidly. Conversely, the short deadline had a substantial impact on the quality of confident responses – when judgment knowledge was conscious.

9. Discussion

The strict response deadline impacted on the quality of responses associated with betting on the grammaticality decision itself (confident responses), i.e.: those made with conscious judgment knowledge. No similar effect was found for responses

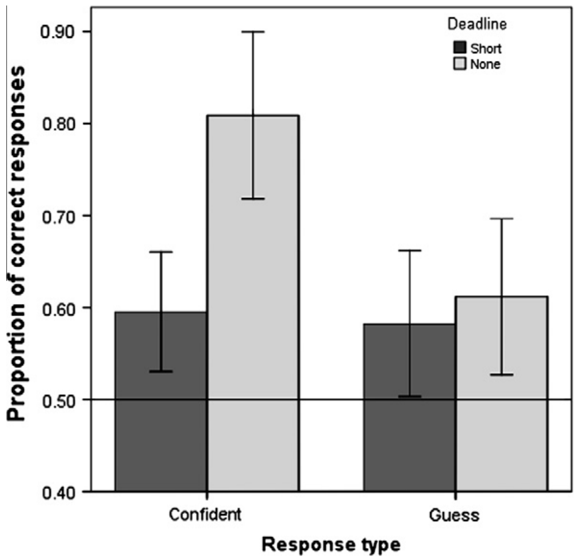

Fig. 2. Accuracy as a function of response type and deadline. Bars represent 95% confidence intervals. The horizontal line shows chance performance.

made in the absence of conscious judgment (guess responses, associated with betting on a random process; though we cannot rule out a similar proportional reduction caused by short vs. no deadline in guess responses as in confident responses). The detectable effect of deadline on confidence rather than guess responses is in accordance with dual-process theories of recognition memory insofar as knowledge that is not accompanied by metacognitive awareness can be elicited rapidly with virtually no decline in quality. The confident response still elicited knowledge under a strict deadline, the accuracy of which was comparable to the guess response. A period of around a second was demonstrably required for an optimal decision when judgment knowledge was conscious; the same was not true of responses made in the absence of conscious judgment knowledge. The results support the no-loss gambling method of measuring the conscious status of knowledge by showing the method picks out different types of knowledge, types that differ in ways consistent with relevant theory (in this case, dual process theory).

Interestingly, participants experienced judgment knowledge as conscious in a similar number of trials under a strict deadline as under no deadline (the short deadline increased guess responses by no more than 8%). An increase in the proportion of guess to confident responses under the strict deadline would have been theoretically plausible: participants may simply not have had time to generate conscious judgment knowledge under the short deadline. However, it seems if conscious judgment knowledge is going to be formed after a second, it will have at least started this process by half a second, allowing some confidence in the judgment. What is impaired by the deadline is not the awareness that some reliable process is being used, but the reliability of that process.

10. General discussion

The first aim of this paper was to improve the methodology of no-loss gambling (Dienes & Seth, 2010) by having the confidence decision (what decision to bet on, grammaticality or a random choice) made at exactly the same time as the grammaticality decision. We showed in two studies that making the two decisions simultaneously led to a clear demonstration of unconscious knowledge by the guessing criterion (60% correct grammaticality choices when willing to bet on a random process rather than the grammaticality decision itself) – in fact, roughly the same amount of unconscious knowledge in terms of accuracy as originally found by Dienes and Seth with their sequential procedure (first grammaticality decision, then confidence). The fact that the simultaneous and sequential procedures yield the same results fits Tunney and Shank's (2003) finding with verbal confidence ratings.

The second aim of the paper was to help validate the method by showing it picked out different knowledge types, types that differed in ways that fitted relevant theory. Indeed, the results presented here are in accordance with dual-process theories of memory (as e.g. interpreted by Dewhurst et al. (2006)). It appears that the longer RTs associated with guess (and perhaps know) responses in R/K experiments are due to the information they afford to metacognitive judgment, not necessarily the knowledge of what has been learned (Dewhurst et al., 2006). When conscious judgment knowledge is not formed, self-paced tests reveal guess responses to be relatively time-consuming compared to when judgment knowledge is conscious. Yonelinas (2002) states that it is unsurprising that responses indexing familiarity are slower than those indexing recollection in R/K studies as participants are often instructed to use the 'know' response if the item is not recollected, i.e. demand characteristics may play an important role in producing RT differences between guess, R and K responses. In effect this means both the familiarity and recollection responses are completed before a ‘know’ or ‘guess’ response is finally given. Similarly, in our case, it would have been fully permissible for participants to opt for rapid guess responses, yet this did not occur, perhaps for similar reasons – people wait to see if structural knowledge reveals itself to them. In fact, for our materials, unconscious judgment knowledge is formed in as good quality as it ever will be by 500 ms, whereas conscious judgment knowledge takes up to a second to fully form, providing a difference that is consistent with dual process theory and that therefore vindicates the measuring method.

The longer RTs for guess than sure responses are consistent with a contrasting single process theory of that difference that can be derived from Scott and Dienes (2010b), and seemingly inconsistent with the single-process theory by Cleeremans and Jimenez (2002) and Destrebecqz and Cleeremans (2001, 2003) who postulated that conscious as opposed to unconscious knowledge takes time to fully form. Scott and Dienes (2010b) present a single model account of conscious and unconscious judgment knowledge when based on unconscious structural knowledge. They found the most rapid RTs to grammaticality judgments were made when those judgments were based on the extremes of subjective familiarity, i.e.: those rated highly familiar or unfamiliar (see also the RT-distance hypothesis; Ashby, Boynton, & Lee, 1994; and also evidence-accumulation models of decision making, e.g.: Lee & Cummins, 2004; Ratcliff, Gomez, & McKoon, 2004; Ratcliff & Starns, 2009). RTs were longer to sequences in which familiarity was close to the mean. Furthermore, it was shown that familiarity predicted grammaticality judgments even when participants reported their decision strategy was a random selection. As a guess response means true indifference between endorsing or rejecting a sequence as grammatical, guesses reflect those responses where the to-be-classified stimulus is close to the mean value of subjective familiarity. Consistently confidence has been shown reliably to correlate inversely with RT in other paradigms (Petrusic & Baranski, 2003, 2009). One explanation of the long RTs for guess rather than sure responses is that discriminating small differences in familiarity takes time. But such a theory would predict that short deadlines would hurt guess responses, contrary to our findings.

Somewhat paradoxically, despite the ‘natural’ time course of responses made with unconscious judgment knowledge being relatively long, this type of response can, when enforced, be made rapidly with little impact on quality. The proportion of accurate responses when betting on a random process under the strict deadline in experiment 2 (.58) was virtually the same as the no deadline (.61) and the self-paced responding of experiment 1 (.61), in support of dual-process theory. Experiment 2 also showed a large reduction in the quality of knowledge made with conscious judgment knowledge under the strict deadline. This helps solve the contradiction between dual process theories of memory and the findings that in self-paced tests unconscious knowledge takes longer to be expressed. Here the emphasis is on *expressed*; i.e.: the conscious judgment, or metacognitive experience, of that knowledge (cf Moscovitch, 2008). Similarly, for the single process theory of Scott and Dienes (2010b), the greater time taken to use small differences of familiarity from the mean is not based on any inherent different time delay in using such differences compared to large ones; those differences can be used just as quickly as large ones. So how are the effects of deadline to be explained?

There are two possible explanations for why the deadline hurt conscious rather than unconscious judgment knowledge. Conscious judgment knowledge can be based on either conscious or unconscious structural knowledge. Thus, one hypothesis is that it is conscious structural knowledge (i.e. knowledge that goes beyond the overall familiarity of a string) that takes time to be fully used, consistent with the dual process models of Scott and Dienes (2010a) and Dienes (2008), and this is why conscious judgment knowledge is overall harmed by a short deadline. As responses based on conscious structural knowledge are generally more accurate than those based on unconscious structural knowledge (e.g.: Dienes & Scott, 2005; Scott & Dienes, 2008, 2010a, 2010b, 2010c) it could be that conscious knowledge is comprised of more complex rules than unconscious knowledge (e.g.: application of higher-order n-grams or longer dependencies) that are inherently time consuming to apply. If responses based on intuition or familiarity (unconscious structural knowledge) are based on simple, or relatively incomplete, knowledge (compared to conscious structural knowledge responses), responses based on this knowledge may take time to be expressed but are as well-formed as they will ever be in a short time Alternatively, unconscious structural knowledge may be embedded in a connectionist network and can be applied with a single pass of activation while conscious structural knowledge may be applied serially. That is, the prediction of this hypothesis is that accuracy for responses with conscious judgment knowledge based on rules and recollections (conscious structural knowledge) would be harmed by a short deadline; but accuracy for responses with conscious judgment knowledge based on intuition and familiarity (unconscious structural knowledge) would be not be harmed by a short deadline.

The second hypothesis is that when the familiarity signal of unconscious structural knowledge is used metacognitively to classify strings, it becomes vulnerable. This may be because higher order representations of the first order familiarity state are linked by re-entrant loops (Edelman, 1989; Kriegel, 2007; Lamme, 2006). Thus if deadlines interfere with the metacognitive process, the first-order state itself becomes modified, and thus the expression of the unconscious structural knowledge becomes distorted. Alternatively, the first order knowledge (familiarity) may not be altered by higher order states (cf Rosenthal, 2000); nonetheless, once higher order states are used metacognitively if they become distorted and misrepresent lower order states, classification performance would be compromised. In either case (a causal integration of first and second order states or a simple misrepresentation of first order states by second order states), the deadline manipulation is predicted to interfere with confident responses based on intuition or familiarity. Of course, in the current experiment guess responses were not accompanied by, or integrated with, higher order states, which is why deadlines had little impact on accuracy. By this explanation, it may even be that conscious structural knowledge can survive the deadline manipulation. Given conscious structural knowledge is symbolic, some noise in its representation can be easily cleaned up (e.g. cf Sun, 2002). However, familiarity is a continuous non-conceptual representation and it is unclear how any noise introduced could be cleaned up – noise in familiarity can only degrade performance that is based on familiarity. Thus, if rules and recollections are particularly simple or strong, conscious structural knowledge could be unaffected by the deadline manipulation. Note that this possibility is opposite to the prediction outlined above, but still relies on a qualitative distinction between conscious and unconscious structural knowledge.

No-loss gambling provides a way of making clear to participants what is meant by a "guess" response – it means no better than random. But one can never be sure that any method always picks out just unconscious knowledge. Maybe people believe they have paranormal abilities (and can 'will' the random process to give a desired answer), or do not understand randomness, or probability match rather than respond optimally with their gambling (cf Shanks, Tunney, & McCarthy, 2002; note we did inform subjects that if they had any confidence in their response, they would gain by betting on it). Any measuring method can be criticised for the mere possibility it might sometimes get it wrong; the acid test is if in practice it gets it right often enough that it participates in theory-driven research, proving itself by the theories it can corroborate.

In sum, this paper has demonstrated the usefulness of no-loss gambling by showing it survives more rigorous testing (simultaneous rather than successive judgments) and distinguishes qualitatively different knowledge types in ways consistent with dual process theory, a theory which is quite independent of the theory that the measurement procedure was based on (higher order thought theory, Dienes, 2008; Rosenthal, 2000). Thus, both theory and measurement pull themselves up by their bootstraps (Seth, Dienes, Cleeremans, Overgaard, & Pessoa, 2008).

References

Ashby, F. G., Boynton, G., & Lee, W. W. (1994). Categorization response time with multidimensional stimuli. *Perception and Psychophysics, 55*, 11–27.

Berry, D. C., & Dienes, Z. (1993). *Implicit learning: Theoretical and empirical issues*. Hove, UK: Erlbaum.

Boldini, A., Russo, R., & Avons, S. E. (2004). One process is not enough! A speed-accuracy tradeoff study of recognition memory. *Psychonomic Bulletin and Review, 11*, 353–361.

Chen, W., Guo, X., Tang, J., Zhu, L., Yang, Z., & Dienes, Z. (2011). Unconscious structural knowledge of form-meaning connections. *Consciousness & Cognition, 20*, 1751–1760.

Cleeremans, A., & Jimenez, L. (2002). Implicit learning and consciousness: A graded, dynamic perspective. In R. M. French & A. Cleeremans (Eds.), *Implicit learning and consciousness* (pp. 1–40). Hove, UK: Psychology Press.

Clifford, C. W. G., Arabzadeh, E., & Harris, J. A. (2008). A good bet to measure awareness? *Trends in Cognitive Sciences, 12*, 210.

Destrebecqz, A., & Cleeremans, A. (2001). Can sequence learning be implicit? New evidence with the Process Dissociation Procedure. *Psychonomic Bulletin & Review, 8*, 343–350.

Destrebecqz, A., & Cleeremans, A. (2003). Temporal effects in sequence learning. In L. Jimenez (Ed.), *Attention and implicit learning* (pp. 181–213). Amsterdam: John Benjamins Publishing Company.

Dewhurst, S. A., & Conway, M. A. (1994). Pictures, images and recollective experience. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*, 1088–1098.

Dewhurst, S. A., Hitch, G. J., & Barry, C. (1998). Separate effects of word frequency and age of acquisition in recognition and recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24*, 284–298.

Dewhurst, S. A., Holmes, S. J., Brandt, K. R., & Dean, G. M. (2006). Measuring the speed of the conscious components of recognition memory: Remembering is faster than knowing. *Consciousness and Cognition, 15*, 147–162.

Dienes, Z. (2004). Assumptions of subjective measures of unconscious mental states. *Journal of Consciousness Studies, 11*, 25–45.

Dienes, Z. (2008). Subjective measures of unconscious knowledge. *Progress in Brain Research, 168*, 49–64.

Dienes, Z., & Altmann, G. (1997). Transfer of implicit knowledge across domains: How implicit and how abstract? In D. Berry (Ed.), *How implicit is implicit learning?* (pp 107–123). Oxford: 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*, 1322–1338.

Dienes, Z., & Scott, R. (2005). Measuring unconscious knowledge: Distinguishing structural knowledge and judgment knowledge. *Psychological Research, 69*, 338–351.

Dienes, A., & Seth, A. (2010). Gambling on the unconscious: A comparison of wagering and confidence ratings as measures of awareness in an artificial grammar task. *Consciousness and Cognition, 19*, 674–681.

Edelman, G. M (1989). *The remembered present: A biological theory of consciousness*. Basic Books.

Fleming, S. M., & Dolan, R. J. (2010). Effects of loss aversion on post-decision wagering: Implications for measures of awareness. *Consciousness and Cognition, 19*, 352–363.

Gaillard, V., Vandenberghe, M., Destrebecqz, A., & Cleeremans, A. (2006). First- and third-person approaches in implicit learning research. *Consciousness and Cognition, 15*, 709–722.

Gardiner, J. M., Ramponi, C., & Richardson-Klavehn, A. (1998). Experiences of remembering, knowing, and guessing. *Consciousness and Cognition, 7*, 1–26.

Gardiner, J. M., Ramponi, C., & Richardson-Klavehn, A. (2002). Recognition memory and decision processes: A meta-analysis of remember, know and guess responses. *Memory, 10*, 83–98.

Guo, X., Zheng, L., Zhu, L., Yang, Z., Chen, C., Zhang, L., et al (2011). Acquisition of conscious and unconscious knowledge of semantic prosody. *Consciousness and Cognition, 20*, 417–425.

Henson, R. N. A., Digg, M. D., Shallice, T., Josephs, O., & Dolan, R. J. (1999). Recollection and familiarity in recognition memory: An event-related functional magnetic resonance imaging study. *The Journal of Neuroscience, 19*, 3962–3972.

Hintzman, D. L., & Caulton, D. A. (1997). Recognition memory and modality judgments: A comparison of retrieval dynamics. *Journal of Memory and Language, 37*, 1–23.

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language, 30*, 513–541.

Johansson, T. (2009). In the fast lane towards implicit learning: Nonanalytic processing and fluency in artificial grammar learning. *European Journal of Cognitive Psychology, 21*, 129–160.

Kahneman, D., & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica, 47*, 263–291.

Koch, C., & Preuschoff, K. (2007). Betting the house on consciousness. *Nature Neuroscience, 10*, 140–141.

Konstantinou, I., & Gardiner, J. M. (2005). Conscious control and memory awareness when recognising famous faces. *Memory, 13*, 449–457.

Kriegel, U. (2007). A cross-order integration hypothesis for the neural correlates of consciousness. *Consciousness and Cognition, 16*, 897–912.

Lamme, V. A. F. (2006). Towards a neural stance on consciousness. *Trends in Cognitive Sciences, 10*, 494–501.

Lee, M. D., & Cummins, T. D. R. (2004). Evidence accumulation in decision making: Unifying the "take the best" and "rational" models. *Psychonomic Bulletin and Review, 11*, 343–352.

Lorch, R. F., & Myers, J. L. (1990). Regression analyses of repeated measures data in cognitive research. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*, 149–157.

Moscovitch, M. (2008). The hippocampus as a "stupid", domain-specific module: Implications for theories of recent and remote memory, and of imagination. *Canadian Journal of Experimental Psychology, 62*, 62–79.
Norman, E., Price, M. C., & Duff, S. C. (2006). Fringe consciousness in sequence learning: The influence of individual differences. *Consciousness and Cognition, 15*, 723–760.
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.
Pasquali, A., Timmermans, B., & Cleeremans, A. (2010). Know thyself: Metacognitive networks and measures of consciousness. *Cognition, 117*, 182–190.
Persaud, N., McLeod, P., & Cowey, A. (2007). Post-decision wagering objectively measures awareness. *Nature Neuroscience, 10*, 257–261.
Petrusic, W. M., & Baranski, J. V. (2003). Judging confidence influences decision processing in comparative judgments. *Psychonomic Bulletin and Review, 10*, 177–183.
Petrusic, W. M., & Baranski, J. V. (2009). Probability assessment with response times and confidence in perception and knowledge. *Acta Psychologica, 130*, 103–114.
Ratcliff, R., Gomez, P., & McKoon, G. (2004). A diffusion model account of the lexical decision task. *Psychological Review, 111*, 159–182.
Ratcliff, R., & Starns, J. J. (2009). Modelling confidence and response time in recognition memory. *Psychological Review, 116*, 59–83.
Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behaviour, 6*, 855–863.
Reber, A. S. (1969). Transfer of syntactic structure in synthetic languages. *Journal of Experimental Psychology, 81*, 115–119.
Rebuschat, P., & Williams, J. (2009). Implicit learning of word order. In N. A. Taatgen & H. van Rijn (Eds.), *Proceedings of the 31st annual conference of the cognitive science society*. Austin, TX: Cognitive Science Society.
Rosenthal, D. M. (2000). Metacognition and higher order thoughts. *Consciousness and Cognition, 9*, 231–242.
Schurger, A., & Sher, S. (2008). Awareness, loss aversion and post-decision wagering. *Trends in Cognitive Sciences, 12*, 209–210.
Scott, R. B., & Dienes, Z. (2008). The conscious, the unconscious, and familiarity. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*, 1264–1288.
Scott, R. B., & Dienes, Z. (2010a). The metacognitive role of familiarity in artificial grammar learning: Transitions from unconscious to conscious knowledge. In A. Efklides & P. Misailidi (Eds.), *Trends and prospects in metacognition research*. New York: Springer.
Scott, R. B., & Dienes, Z. (2010b). Fluency does not express implicit knowledge of artificial grammars. *Cognition, 114*, 372–388.
Scott, R. B., & Dienes, Z. (2010c). Knowledge applied to new domains: The unconscious succeeds where the conscious fails. *Consciousness and Cognition, 19*, 391–398.
Seth, A. K., Dienes, Z., Cleeremans, A., Overgaard, M., & Pessoa, L. (2008). Measuring consciousness: Relating behavioural and neurophysiological approaches. *Trends in Cognitive Sciences, 12*, 314–321.
Shanks, D. R., Tunney, R. J., & McCarthy, J. (2002). A re-examination of probability matching and rational choice. *Journal of Behavioral Decision Making, 15*, 233–250.
Sun, R. (2002). *Duality of the mind: A bottom-up approach toward cognition*. Erlbaum.
Tulving, E. (1985). Memory and consciousness. *Canadian Psychology, 26*, 1–12.
Tunney, R. J. (2007). The subjective experience of remembering in artificial grammar learning. *European Journal of Cognitive Psychology, 19*, 934–952.
Tunney, R. J., & Shanks, D. R. (2003). Subjective measures of awareness and implicit cognition. *Memory and Cognition, 31*, 1060–1071.
Turner, C. W., & Fischler, I. S. (1993). Speeded tests of implicit knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*, 1165–1177.
Wan, L., Dienes, Z., & Fu, X. (2008). Intentional control based on familiarity in artificial grammar learning. *Consciousness and Cognition, 17*, 1209–1218.
Wixted, J. T., & Mickes, L. (2010). A continuous dual-process model of remember/know judgments. *Psychological Review, 117*, 1025–1054.
Yonelinas, A. P. (2002). The nature of recollection and familiarity: A review of 30 years of research. *Journal of Memory and Language, 46*, 441–517.