Consciousness and Cognition xxx (2009) xxx–xxx

Contents lists available at ScienceDirect

Consciousness and Cognition

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

Gambling on the unconscious: A comparison of wagering and confidence ratings as measures of awareness in an artificial grammar task ☆

Zoltán Dienes [a,*], Anil Seth [b]

[a] Department of Psychology, University of Sussex, Brighton BN1 9QG, UK
[b] Department of Informatics, University of Sussex, Brighton BN1 9QJ, UK

ARTICLE INFO

Article history:
Received 27 January 2009
Available online xxxx

Keywords:
Unconscious knowledge
Subjective measures
Wagering
Confidence
Subjective threshold
Artificial grammar learning
Implicit learning
Consciousness
Higher order thoughts

ABSTRACT

We explore three methods for measuring the conscious status of knowledge using the artificial grammar learning paradigm. We show wagering is no more sensitive to conscious knowledge than simple verbal confidence reports but is affected by risk aversion. When people wager rather than give verbal confidence they are less ready to indicate high confidence. We introduce a "no-loss gambling" method which is insensitive to risk aversion. We show that when people are just as ready to bet on a genuine random process as their own classification decisions, their classifications are still above baseline, indicating knowledge participants are not aware of having. Our results have methodological implications for any study investigating whether people are aware of knowing.

© 2009 Elsevier Inc. All rights reserved.

How can we tell if a person is aware of being in a mental state? For example, how can we tell if a person is aware of knowing? This is a crucial question for researchers interested in consciousness, and has been a core question in the fields of subliminal perception and implicit learning (Seth, Dienes, Cleeremans, Overgaard, & Pessoa, 2008). For example, Merikle (2007) defined subliminal perception as seeing without being aware of seeing, and Dienes (2008a) argued that implicit learning was a mechanism that produces knowledge one is not aware of. Further, if one accepts the proposal that unconscious mental states are mental states one is not aware of being in (Rosenthal, 2005), then any methodology for determining the conscious status of knowledge should measure as directly as possible whether or not the person is aware of knowing. Even if one does not subscribe to such 'higher-order' theories of consciousness (e.g. Block, 2001), determining when a person is aware of knowing still remains of theoretical and applied importance. Measuring awareness of being in a mental state is therefore a key issue whatever *a priori* assumptions about consciousness one holds (Seth et al., 2008).

On the face of it, the most direct way of measuring awareness of being in a mental state is to ask a person whether they are in that mental state. Just so, verbal confidence ratings ask the person to indicate whether they are guessing or know to some degree. When a person says that they are literally guessing, that they know nothing, then the person is, on the face of it, not aware of knowing. In fact, when people say they are literally guessing, they can still discriminate stimuli at above chance levels in certain perceptual tasks (e.g. Weiskrantz, 1997) and they can still discriminate whether letter and other sequences have a certain structure in implicit learning paradigms (e.g. Dienes & Altmann, 1997; for a review see Dienes, 2008a). These results satisfy the *guessing criterion* of unconscious knowledge (Dienes, Altmann, Kwan, & Goode, 1995): When the person

☆ This article is part of a special issue of this journal on commentary invited.

* Corresponding author. Fax: +44 1273 6785058.
E-mail address: dienes@sussex.ac.uk (Z. Dienes).

1053-8100/$ - see front matter © 2009 Elsevier Inc. All rights reserved.
doi:10.1016/j.concog.2009.09.009

Please cite this article in press as: Dienes, Z., & Seth, A. Gambling on the unconscious: A comparison of wagering and confidence ratings as measures of awareness in an artificial grammar task. *Consciousness and Cognition* (2009), doi:10.1016/j.concog.2009.09.009

claims to be guessing they have above baseline discrimination performance. Similarly, if a person cannot tell what mental state they are in, there should be no relation between confidence and accuracy: This is the *zero correlation criterion* of unconscious knowledge (Dienes et al., 1995), and has been applied to both subliminal perception (Kolb & Braun, 1995; Kunimoto, Miller, & Pashler, 2001) and implicit learning (e.g. Dienes & Longuet-Higgins, 2004; Johansson, 2009; Tunney, 2005; for a review see Dienes, 2008a).

Verbal confidence reports may have face validity for human adults as a measure of awareness of knowing, but they are problematic for at least young children and non-human animals (e.g. Seth, Baars, & Edelman, 2005). Ruffman, Garnham, Import, and Connolly (2001) wished to apply the confidence measures methodology of Dienes et al. (1995) to the question of whether three-year olds might have an unconscious theory of mind before they have a conscious one. However, a three-year old may not properly understand what confidence terms mean. So Ruffman et al. asked children to gamble tokens on different choice alternatives, showing that children's gambling could be sensitive to objective probabilities but not false belief task choices. The amount a child was willing to gamble (children had 10 tokens to distribute among the choices) was taken to be a measure of subjective probability or confidence. Thus, the results indicate a lack of awareness of knowing the correct answer by the zero correlation criterion (lack of positive relation between gambling and correctness of answer). Similarly, Shields, Smith, Guttmannova, and Washburn (2005), Son and Kornell (2005), and Kornell, Son, and Terrace (2007) used gambling to determine whether Rhesus monkeys were aware of knowing. They trained Rhesus monkeys to wager differing amounts of tokens on their perceptual and memory judgments, showing a relation between amount wagered and accuracy: This is conscious knowledge by the zero correlation criterion if we accept wagering as indicating awareness of knowing. With the same assumption, their data also indicated unconscious knowledge by the guessing criterion, in that when Rhesus monkeys wagered the lowest amount, they were still significantly and substantially above chance baseline.

Shields et al. (2005) used the same wagering method with adult humans as they had used with Rhesus macaques to show analogous cross-species effects. But is there any advantage in using wagering over verbal confidence in showing awareness of knowing in adult humans with well developed linguistic abilities? Like Shields et al., Persaud et al. asked adult humans to wager either a small or large amount (e.g. one versus two tokens) on the correctness of a decision. If the decision was correct the participant won the amount they wagered; if the decision was incorrect, the participant lost the amount wagered. Unlike Shields et al., Persaud, McLeod, and Cowey (2007) argued that wagering constitutes a gold standard for measuring awareness (cf. also Koch & Preuschoff, 2007, and contrast Seth, 2008). We will address in this paper the question of whether such wagering constitutes the most sensitive measure we have of the conscious status of knowledge, that is, of whether people are aware of knowing.

Is there a reason to expect wagering rather than verbal confidence as being more direct, intuitive or sensitive as a measure of the conscious status of knowledge, as Persaud et al. claim? Verbal confidence can be susceptible to bias: People may *think* they know to some degree but *say* they know nothing at all. Of course, people can also *think* they know to some degree, and only wager low. Conversely one can wager high as a guess. Yet, if a conviction in a belief is to be shown in any way, it may plausibly be shown by the amount one is willing to stake on it. And when an amount of money is thrown down on the table, surely it lays public one's convictions not only to others but also to oneself. So gambling may often go hand-in-hand with awareness of one's own convictions; and hence, if those convictions are reliably caused, of one's states of knowing. Still, some forms of gambling may be better in this role than others (cf. Mellor, 1971, 1991).

On what grounds can it be argued that specifically wagering measures awareness of knowing? The expected pay off from a wager is the subjective probability of being correct multiplied by the amount of the wager. Consequently, if a person is aware of knowing to any degree, they should always go for the highest wager. Thus, the use of a low wager implies the person thinks they know nothing. This seems a somewhat sophisticated train of reasoning and it is not clear people directly or intuitively grasp it. For example, Shields et al. (2005) asked people to wager one, two or three tokens, where one won or lost the amount wagered. In terms of expected pay off, if one had any confidence at all, one should always go for the highest wager. If one had no confidence at all, then from the person's point of view, the amount wagered does not matter. However people were more accurate for medium than low wagers, indicating people were not wagering optimally (in terms of expected pay off of tokens) given their confidence.

One explanation for suboptimal wagering performance is that wagering likely involves trial by trial considerations of risk (or loss) aversion. For example, the prospect of losing \$10 is often considered more salient than the prospect of winning the same amount (Kahneman & Tversky, 1979). These considerations are extra to whether or not one is aware of knowing; one could for example wager low even though one had some confidence in order to minimise loss. On this argument, verbal confidence rather than wagering may be the more direct and intuitive measure of awareness of knowing. In the following experiments we use a simple measure of risk aversion to determine empirically whether or not confidence or wagering are sensitive to risk aversion.

Persaud et al. used artificial grammar learning (Reber, 1967, 1989) as a task to produce knowledge that could be conscious or unconscious: Participants memorised strings of letters, which unbeknownst to participants were generated by a set of rules. Participants were then informed of the existence of rules, though not what they were, and were asked to classify new strings as obeying the rules or not. We already know that people perform at above baseline levels when they believe they are guessing (by their verbal report), indicating some unconscious knowledge by the guessing criterion, and typically (though not always) people also show a relation between confidence and accuracy, showing some conscious knowledge by the zero correlation criterion (e.g. Dienes et al., 1995). Persaud et al. showed the same conclusions follow with wagering: People perform at above chance levels when they use the low wager, indicating unconscious knowledge by the guessing cri-

ARTICLE IN PRESS

terion, and they show higher accuracy for high rather low wagers, indicating some conscious knowledge by the zero correlation criterion. We use the artificial grammar learning paradigm in two experiments to compare the measurement properties of verbal confidence and gambling. In Experiment 1 we investigate the wagering used by Persaud et al. and in Experiment 2 we consider another gambling measure of confidence, taken from the literature on the philosophy of subjective probability (Dienes, 2008b; Hacking, 2001).

1. Experiment 1

Experiment 1 used an artificial grammar learning paradigm with two groups of participants: One group wagered high or low on their decision and the other gave a binary confidence judgment ('guess' vs. 'sure'). When a person is aware of knowing, they know when they know and when they are guessing. That is, a good measure of awareness of knowing will correlate with accuracy if there is any awareness of knowing at all (see Dienes, 2004; Dienes & Perner, 2004, for assumptions). Thus, the more sensitive a measure of awareness of knowing is, the stronger will be the relationship between the measure and accuracy (e.g. Tunney & Shanks, 2003). The aim of Experiment 1 was to determine whether wagering has a stronger relation with accuracy than confidence does. In addition participants were given a test of risk aversion (Hartog, Ferrer-i-Carbonell, & Jonker, 2000); we predicted risk aversion would correlate with wagering as a measure of awareness, but not with verbal confidence as a measure of awareness.

2. Method

2.1. Participants

Seventy University of Sussex students aged between 20 and 23 were assigned to one of the two groups such that the wagering group had 40 participants and the verbal confidence group 30.

2.2. Materials

Participants were trained on one of two grammars in order to employ the two grammar design of Dienes and Altmann (1997). In the training phase, half the participants are were asked to memorise strings of letters generated by one grammar (grammar 'A') and the other half of the participants were asked to memorise strings of letters generated by another grammar ('B'). The test set consisted of an equal mix of A and B strings so that the strings which were grammatical for half the participants were ungrammatical for the other half. Thus, the appropriate baseline performance in the test phase is 50%. The two grammars (A and B) and the exact training and test strings used were those used by Dienes and Scott (2005, Experiment 2). The grammars were originally used by Reber (1969). The elements of the grammars were the letters M, T, V, R, and X. The generated strings were between 5 and 9 letter in length. The training phase consisted of 15 strings presented three times in a different random order each time (the same random order for each participant). The test consisted of 30 new letter strings from each grammar. See Dienes and Scott (2005, Appendix A) for a complete listing of the materials. A fixed order of test items was used; half the participants received the test items in that order, and half in the reverse order.

Microsoft PowerPoint was used to present both training and test strings. Each string was presented on a separate slide displayed centrally in black text (Times New Roman font size 40) on a white background. The PowerPoint presentation for the training phase displayed each string for 5 s followed by a blank screen for a further 5 s. The presentation for the testing phase allowed participants to advance through the strings at their own pace.

2.3. Procedure

For the training phase, participants were required to memorise each string while it was displayed and to write down what they could remember while the screen was blank. For the test phase, participants were informed that the order of letters in the strings seen during the training phase had obeyed a complex set of rules and that exactly half of the strings they were about to see obeyed the same rules. For each string, participants were required to indicate whether or not it obeyed the rules, and then to wager or to give their confidence (depending on the group). Participants in the wagering group were told at the beginning of the test phase that they started with 10 sweets. Then on each trial they indicated whether they wished to wager one or two sweets (their choice of Smarties or Haribo). They were told that if they were correct they would gain the amount wagered, but if they were incorrect they would lose that amount. Participants did not learn what they had won or lost until the end of the test phase, at which point they were given their earnings. No participant had to pay any sweets if they ended in debt. Participants in the confidence group indicated on each trial whether they were guessing or sure to some degree; guessing was defined as having no knowledge whatsoever, their answer was as good as flipping a coin.

At the end of the experiment the last 50 participants run were given a test of risk aversion (Hartog et al., 2000). Specifically they were asked: "If there was a lottery for a 10 £ prize, which will be given to one of the 10 ticket holders, how much would you pay for a ticket? The 'mathematical' answer might seem to be 'one pound' because you have a 1/10 chance to win 10 £. But there is no right answer because you might not wish to certainly give up one pound for the mere probability of

Please cite this article in press as: Dienes, Z., & Seth, A. Gambling on the unconscious: A comparison of wagering and confidence ratings as measures of awareness in an artificial grammar task. *Consciousness and Cognition* (2009), doi:10.1016/j.concog.2009.09.009

getting something back. So think about what you personally would really be willing to pay – it is purely down to personal preference.' Then participants were asked "If the prize were 100 £, which will be given to one of the 10 ticket holders, how much would you pay for a ticket?" The smaller the number to either question is given, the more risk averse they are. The second question involves a greater element of risk. For simplicity, we summed the two answers together to get an overall measure of risk aversion.

3. Results

α was at .05 for all analyses. The overall percent correct classification was 65% (SE = 1.9%) for the wagering group and 67% (SE = 2.2%) for the verbal confidence group, which did not differ significantly, $t(68) = 0.64$, 95% CI [−7.6, 3.9]. Each group differed significantly from a chance baseline of 50%, *t*s of 7.89 and 7.28 respectively. Thus, participants in both groups learnt to discriminate the two grammars to about the same degree.

Fig. 1 shows the percent correct classification of grammaticality for low and high confidence for each group. Overall, collapsing across whether people wagered or gave verbal confidence, people classified more accurately when they had high (73%) rather than low (60%) confidence, $t(68) = 7.57$. This 13% difference in accuracy between high and low confidence we will call the *slope* measure of the confidence–accuracy relationship. The fact that slope is greater than zero indicates conscious knowledge by the zero correlation criterion. Crucially, the difference in slopes between wagering (10.5, SE = 2.18) and verbal confidence (15.2, SE = 2.63) was not significant, $t(68) = 1.41$, 95% CI [−11.5%, 2.0%]. The confidence interval indicates that we can reject a slope for wagering that is larger than for verbal confidence by any more than 2%. That is, to a high degree of sensitivity, we can assert that wagering is not more sensitive than verbal confidence for measuring awareness of knowing.

Both wagering and verbal confidence measures indicate unconscious knowledge by the guessing criterion, as shown in Fig. 1 (the 95% confidence interval on accuracy for just the low confidence responses excludes 50% for both wagering and verbal confidence).

We also measured the confidence–accuracy relationship with Type II d', which takes a hit to be a high confidence response when the grammaticality classification was correct and a false alarm to be a high confidence response when the classification was incorrect. That is, Type II d' measures the ability of the participant to distinguish states of correctness (and thus, different states of knowledge) by their confidence: i.e. it is another way of operationalising the zero correlation criterion. Logistic Type II d' was 0.33 (SE = .07) for wagering and 0.46 (SE = .08) for verbal confidence, both significantly above zero, indicating conscious knowledge by both confidence measures according to the zero correlation criterion. Crucially the d's did not differ significantly, $t(68) = 1.16$, 95% CI [−.61, .16]. The confidence interval shows that we can rule out wagering having a higher d' than verbal confidence by any amount above 0.16. That is, to a high degree of sensitivity, we can assert that wagering is not more sensitive than verbal confidence for measuring awareness of knowing.

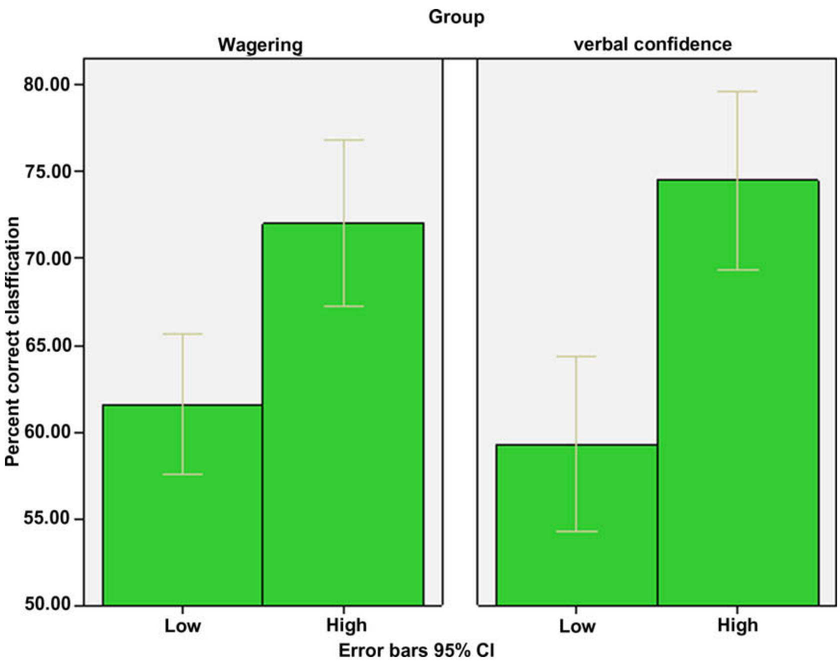

Fig. 1. Percent correct scores for Experiment 1.

The proportion of low confidence responses was higher for wagering (63%, SE = 2.0%) than for verbal confidence (46%, SE = 3.1), $t(68) = 4.61$, indicating people were more willing to express some confidence verbally than with wagering.

As would be expected, slope and Type II d' correlated highly, $r = .94$ ($N = 70$). Thus, on current evidence, it does not seem to matter whether the zero correlation criterion is operationalised as slope or d' (see Dienes, 2008a for discussion of these and other measures of the zero correlation criterion). Evans and Azzopardi (2007) criticised Type II d' measures because in their study they found it correlated with bias; in our study, neither slope nor Type II d' correlated significantly with the proportion of low confidence responses, *r*s of .19 and .23, respectively.

The optimal score on the risk aversion measure, showing no risk aversion, is 11. The lower the number below 11 the greater the risk aversion. The wagering group's risk aversion was 8.3 (SE = 0.99) and the verbal confidence group's was 9.6 (SE = 1.23). For the wagering group the correlation between risk aversion and Type II d' was significant, $r(N = 30) = .52$, and between risk aversion and slope marginally so, $r = .32$, $p = .091$. That is, the more risk averse a person was, the lower the measured amount of conscious knowledge using wagering. On the other hand, when verbal confidence was used the correlations were non-significant, −.28 and −.30 respectively ($N = 20$). For Type II d' the correlation was significantly higher for wagering than for verbal confidence, $z = 2.79$, and for slope the correlation was also significantly higher for wagering than for verbal confidence, $z = 2.07$.

In the verbal confidence group, risk aversion did not detectably correlate either with the percentage correct when confidence was low (guessing criterion measure of unconscious knowledge), $r = .22$, 95% CI [−.25, .60], nor with the percentage correct when confidence was high, $r = -.05$, 95% CI [−.48, .40]. In the wagering group, risk aversion also did not detectably correlate with percentage correct when wagering low, $r = .28$, 95% CI [−.09, .58]; in contrast, risk aversion did correlate with percentage correct when wagering high, $r = .50$. That is, the higher the risk aversion the lower the accuracy when high wagers were used: High wagers may be precisely the time a high risk averse person is most anxious.

4. Discussion

Experiment 1 indicated that any claim that wagering is more sensitive than verbal confidence as a general measure of awareness of knowing can be ruled out to a high degree of sensitivity (compare numerically similar results in Table 3 of Persaud & McLeod, 2008). In fact, people were substantially more likely to indicate some confidence with a verbal confidence response rather than with wagering. This is not surprising given that wagering, more so than verbal confidence, is in principle susceptible to the affects of risk aversion. A person can wager low in order to avoid large losses, regardless of whether they have some confidence in their answer. Indeed, we found a measure of risk aversion correlated with the measured amount of conscious knowledge when wagering was used, but not when verbal confidence was used. Empirically, wagering as a measure of the conscious status of knowledge depends on how risk or loss averse a person is.

Persaud et al. (2007) used substantial real money wagers (£1 vs. £2) in two of their studies. It may be that real money increases motivation and hence the sensitivity of wagering to conscious knowledge. On the other hand, real money may increase the influence of risk aversion on wagering, decreasing the sensitivity of wagering to conscious knowledge. In their artificial grammar learning study with one or two pound wagers, the slope of the accuracy–confidence relation was 8%, numerically no greater than the 11% slope we found using sweets. That is, sweets are just as effective as substantial money wagers in discriminating states of knowing from guessing. Other studies in Persaud et al. used only token money. In contrast with token money, but like real money, sweets provide real losses and gains.

Mellor (1971, 1991) argued that a good measure of the strength of conscious belief is not the amount wagered for fixed odds (as we did in Experiment 1) but by the odds for an unknown stake and direction of bet, because the latter reduces the impact of psychological factors that could affect wagering but do not reflect strength of conscious beliefs. Hacking (2001) and Dienes (2008b) illustrated subjective probabilities with a different method that is easier for people to intuitively grasp than Mellor's yet also deals with the problems with wagering. Indeed, the method is really a way of making concrete the instructions given with verbal confidence measures. When we ask people to give a confidence rating it is important that they understand precisely what we want them to understand the different ratings to mean. The scale points of a 1–7 confidence scale labelled from 'not very confident' to 'very confident' are open to different interpretations by different participants. To determine if people know something when they believe they know nothing at all (the guessing criterion of unconscious knowledge), the confidence rating for 'guessing' must be clearly defined – not just "not very confident", for example. We have standardly (e.g. Dienes & Scott, 2005; Dienes et al., 1995) made clear to participants 'guessing' means "you know nothing at all – you could just as well flipped a coin to determine your answer". The natural extension of these instructions is to actually flip a coin, or use some other equivalent process that is transparently random, and see if participants are indifferent between betting on a coin flip and their grammaticality decision.

The typical objection to verbal confidence is that people may use terms like 'guessing' in idiosyncratic ways (Reingold & Merikle, 1993). Indeed, in everyday life the term 'guessing' allows a range of feelings of confidence. Apparent evidence for unconscious knowledge with the guessing criterion may arise only because of trials in which 'guessing' was used liberally by the participant when they were in fact aware of some degree of conviction (see Dienes, 2008a for discussion). However, if a person chooses to bet on a transparently random process rather than their own decision, the argument that the participant is using 'guessing' in an idiosyncratic way loses its force. Participants show what they mean by putting their money where their mouth is.

5. Experiment 2

Experiment 2 was similar to Experiment 1 except that only one form of confidence was taken, which we call no-loss gambling. After each grammaticality classification, the participant shuffled two cards and chose one. One of the cards had a reward (a sweet) indicated on its back and the other card did not. The participant was then asked which choice did they wish to bet on: The grammaticality decision or the card. If they were correct on their choice, they would gain a sweet. If they were incorrect, they lost nothing. Thus, there is no question of risk aversion because the participant never has an opportunity to lose sweets. The meaning of the choices should also be transparent, unlike with wagering. When the participant chooses to bet on the card, they have had every opportunity to appreciate they are betting on a random process rather their own classification decision: The participant is saying they are guessing in a clear way.

6. Method

6.1. Participants

Thirty University of Sussex students aged between 20 and 23 took part in the experiment; they were in fact run at the same time as the participants in Experiment 1.

6.2. Materials

Same as Experiment 1.

6.3. Procedure

The same for experiment one with the exception only one form of confidence was taken. After participants classified a letter string, and were also asked to choose between two face-down cards, one of which had "SWEET" and the other had "NO SWEET" written on the face. Participants were asked whether they would like to either stay with their decision on the letter string which if correct would win a sweet, or turn-over their chosen card in an attempt to win a sweet. If they felt it did not matter which option they chose, they were asked to choose the card option (contrast wagering where a complete lack of confidence allows the participant to be indifferent between wagers). The cards were then shuffled by the experimenter, and then by the participant. Note we ensured that both the classification and card tasks involved active choices by the participant to eliminate potential biases against passively determined outcomes. Participants received their winnings in sweets at the end of the experiment.

7. Results

Overall classification performance was 71% (SE = 2.0%), significantly above 50%, $t(29) = 10.45$, indicating participants had learnt to discriminate the grammars.

Classification performance was 58% (SE = 2.6%) when participants bet on the cards, indicating unconscious knowledge by the guessing criterion, $t(29) = 3.23$, when problems of bias have been minimised. Classification performance was 75% (SE = 2.3%) when people preferred to bet on their classification. So slope is 17% (SE = 3.1%), significantly above zero, $t(29) = 5.38$, indicating conscious knowledge by the zero correlation criterion. Slope was not significantly different from the verbal confidence group of Experiment 1 (17% vs. 15%), $t(58) = 0.39$, 95% CI [−6.6, 9.8], but was marginally higher than the wagering group of Experiment 1 (17% vs. 10%), $t(58) = 1.73$, $p = .089$. That is, no-loss gambling is as sensitive as verbal confidence.

The proportion of low confidence responses (i.e. bets on the cards) was 28% (SE = 1.9%), significantly different from the percentage of low responses both for verbal confidence in Experiment 1 (46%), $t(58) = 5.00$, and for the wagering group of Experiment 1 (63%), $t(68) = 12.33$. That is, people were most likely to indicate confidence with no-loss gambling compared to verbal confidence and wagering.

Average risk aversion was 8.7 (SE = .123). Risk aversion did not correlate with slope, $r(N = 30) = .04$, 95% CI [−.03, .11]. The 95% confidence interval indicates we can reject any correlation with risk aversion above .11, i.e. we can to a high degree of sensitivity rule out risk aversion influencing no-loss gambling as a measure of conscious knowledge.

8. Discussion

Experiment two introduced a no-loss gambling task that makes the meaning of 'guess' transparent. Importantly, when bias in interpretation of the meaning of 'guess' was thus minimised, the guessing criterion still indicated that people can know without being aware of knowing. Further, the confidence–accuracy relationship was of the same magnitude as with verbal reports and was marginally significantly stronger than with wagering. The tendency to state high confidence was also especially high when gambling on cards compared to verbal confidence and wagering. Although an apparently 'high confi-

Please cite this article in press as: Dienes, Z., & Seth, A. Gambling on the unconscious: A comparison of wagering and confidence ratings as measures of awareness in an artificial grammar task. *Consciousness and Cognition* (2009), doi:10.1016/j.concog.2009.09.009

dence' response in no-loss wagering may simply indicate indifference between the random process and grammaticality judgments, the tendency to indicate more confidence in no-loss gambling may appeal to researchers shy of over-estimating the amount of unconscious knowledge. No-loss gambling was designed to minimise risk aversion which was confirmed empirically. In sum, no-loss gambling shows how gambling can successfully be used to indicate awareness of knowing, with implications for measuring awareness of knowing in children and non-human animals as well as adults.

9. General discussion

People show by their ability to discriminate the strings from two grammars that they are, in some sense, aware of properties that distinguish the grammars (Dienes & Seth, 2010; Seth et al., 2008). That is, such first-order awareness is knowledge that allows adaptive discriminations of states in the world (just as the sight of a blindsight patient does). Depending on one's theoretical perspective (Seth et al., 2008), such first-order awareness could constitute phenomenal or primary consciousness, at least when perception is involved (Block, 2001; Snodgrass, Bernat, & Shevrin, 2004; Snodgrass & Shevrin, 2006) or alternatively an unconscious mental state (Rosenthal, 2005).

How can we test whether people are aware of this first-order knowledge? We contrasted three techniques for measuring awareness of knowing. We argued wagering is susceptible to psychological factors irrelevant to awareness of knowing (cf. Clifford, Arabzadeh, & Harris, 2008; Mellor, 1971, 1991; Schurger & Sher, 2008) and presented data that wagering was no more sensitive than verbal confidence reports as a measure of awareness of knowing. Yet wagering involved a more cautious use of high confidence, so may be less useful than verbal reports in convincing sceptics of the existence of knowledge a person is not aware of. On the other hand, a no-loss gambling method involved the least caution in using high confidence responses. When bias in the interpretation of 'guess' was minimised because people bet on an actual random process, people could still have knowledge, indicating unconscious knowledge by the guessing criterion. Of course, people's understanding of random processes can be faulty, and no measurement method *a priori* proves itself worthy (Chang, 2004; Seth et al., 2008). It is only by behaving well in theoretically motivated ways that any measure proves itself (see Dienes, 2008a, for a relevant discussion of this point for subjective measures in implicit learning research).

In order to replicate Persaud et al. (2007) closely, we used their binary wagering, and hence also used a binary confidence scale to make a fair comparison, and a binary choice in no-loss gambling. Whether or not a binary scale is most sensitive is a matter of debate (cf. Overgaard, Fehl, Mouridsen, Bergholt, & Cleeremans, 2008; Overgaard, Rote, Mouridsen, & Ramsøy, 2006; Sergent & Dehaene, 2004 in the domain of perception). While e.g. Dienes et al. (1995) and Dienes and Altmann (1997) used a continuous 50–100% verbal confidence scale, Tunney and Shanks (2003) and Tunney (2005) found that a binary confidence scale was more sensitive. Dienes (2008a) found little to distinguish a variety of different confidence scales in the confidence–accuracy correlations in artificial grammar learning. However, with continuous scales, performance does improve gradually as confidence increases indicating people can make finer discriminations in their states of knowledge than just a binary one, at least when overall performance is good. The no-loss gambling method could be extended to different degrees of confidence by the participant choosing between their grammaticality choice and different card combinations, e.g. two cards providing a sweet and one that does not (cf. Hacking, 2001). Nonetheless, the most interesting choice for most researchers interested in the unconscious will be the one we gave participants: Between a completely random 50:50 process and their grammaticality (or perceptual) judgment.

Confidence and gambling can both be used to measure whether people have higher order thoughts about knowing, that is, whether they are aware of knowing. Not everyone accepts the intuition that conscious knowledge is knowledge one is conscious of (contrast e.g. Cleeremans, 2008; Dienes & Perner, 1999; Rosenthal, 2005, with Block, 2001; Seth, 2008; see Seth et al., 2008). Absent such acceptance, our results are still important for establishing the presence of reflexive, 'higher-order', meta-, or introspective-consciousness, although on this view neither gambling performance nor confidence ratings can be taken as *necessary* for conscious knowledge *per se* (Seth, 2008, see Seth et al., 2008). Moreover, while it may be natural to take a person *saying* they have knowledge when they do as *sufficient* for indicating conscious knowledge, the same may not apply to gambling. For example, it may be possible for animals (and perhaps humans) to learn implicitly to gamble, and it is certainly possible for simple machine learning algorithms to learn advantageous wagering without being conscious (Cleeremans, Timmermans, & Pasquali, 2007). Gambling nonetheless has a clear purpose for measuring awareness of knowing in children and non-human animals: The fact that one can claim to have evidence for both conscious and unconscious knowledge in young children and monkeys is remarkable, even though the necessity and sufficiency of this evidence rests on further assumptions. Whatever *a priori* position one adopts, the distinction between knowledge one is or is not aware of is an important divide in nature with applied and theoretical significance (Dienes & Seth, 2010).

This paper has dealt solely with the conscious status of what Dienes and Scott (2005) called judgment knowledge, e.g. knowledge that a string is or is not grammatical (or, in subliminal perception experiments, e.g. the judgement that a certain word was flashed on the screen). Judgement knowledge can be conscious even as the knowledge of the structure of the training strings that allowed such judgements remains unconscious. Dienes and Scott (2005) present a method for determining the conscious status of structural knowledge (see also Dienes, 2008a).

While no-loss gambling and verbal confidence behaved similarly in the current experiments in terms of insensitivity to risk aversion, the use of gambling has some advantages over verbal confidence. As Persaud et al. (2007) indicate, participants find experiments with gambling fun. Gambling also has an intuitive appeal to researchers and its use may encourage more

Please cite this article in press as: Dienes, Z., & Seth, A. Gambling on the unconscious: A comparison of wagering and confidence ratings as measures of awareness in an artificial grammar task. *Consciousness and Cognition* (2009), doi:10.1016/j.concog.2009.09.009

people to study consciousness. No-loss gambling can also in principle be used with children and non-human animals. We encourage researchers to use both verbal confidence measures where convenient and no-loss gambling where appropriate.

References

Block, N. (2001). Paradox and cross purposes in recent work on consciousness. *Cognition, 79*, 197–219.
Chang, H. (2004). *Inventing temperature: Measurement and scientific progress*. Oxford University Press.
Cleeremans, A. (2008). Consciousness: The radical plasticity thesis. In R. Banerjee & B. K. Chakrabarti (Eds.), *Progress in brain science* (Vol. 168, pp. 19–33).
Cleeremans, A., Timmermans, B., & Pasquali, A. (2007). Consciousness and metarepresentation: A computational sketch. *Neural Networks, 20*, 1032–1039.
Clifford, C. W., Arabzadeh, E., & Harris, J. A. (2008). Getting technical about awareness. *Trends in Cognitive Sciences, 12*, 54–58.
Dienes, Z. (2004). Assumptions of subjective measures of unconscious mental states: Higher order thoughts and bias. *Journal of Consciousness Studies, 11*, 25–45.
Dienes, Z. (2008a). Subjective measures of unconscious knowledge. *Progress in Brain Research, 168*, 49–64.
Dienes, Z. (2008b). *Understanding psychology as a science: An introduction to scientific and statistical inference*. Palgrave Macmillan.
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., Kwan, L., & Goode, A. (1995). Unconscious knowledge of artificial grammars is applied strategically. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 21*, 1322–1338.
Dienes, Z., & Seth, A. (2010). The conscious and the unconscious. In G. Koob, R. F. Thompson, & M. Le Moal (Eds.), *Encyclopedia of behavioral neuroscience*. Elsevier.
Dienes, Z., & Longuet-Higgins, H. C. (2004). Can musical transformations be implicitly learned? *Cognitive Science, 28*, 531–558.
Dienes, Z., & Perner, J. (1999). A theory of implicit and explicit knowledge. *Behavioural and Brain Sciences, 22*, 735–755.
Dienes, Z., & Perner, J. (2004). Assumptions of a subjective measure of consciousness: Three mappings. In R. Gennaro (Ed.), *Higher order theories of consciousness* (pp. 173–199). John Benjamins Publishers: Amsterdam.
Dienes, Z., & Scott, R. (2005). Measuring unconscious knowledge: Distinguishing structural knowledge and judgment knowledge. *Psychological Research, 69*, 338–351.
Evans, S., & Azzopardi, P. (2007). Evaluation of a 'bias-free' measure of awareness. *Spatial Vision, 20*, 61–77.
Hacking, I. (2001). *Probability and inductive logic*. Cambridge University Press.
Hartog, J., Ferrer-i-Carbonell, A., & Jonker, N. (2000). On a simple survey measure of individual risk aversion. *CESifo working paper series, CESifo working paper no. CESifo GmbH*.
Johansson, T. (2009). In the fast lane toward structure in implicit learning: Non-analytic 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, K., & Preuschoff, K. (2007). Betting the house on consciousness. *Nature Neuroscience, 10*, 140–141.
Kolb, F. C., & Braun, J. (1995). Blindsight in normal observers. *Nature, 377*, 336–338.
Kornell, N., Son, L. K., & Terrace, H. S. (2007). Transfer of metacognitive skills and hint seeking in monkeys. *Psychological Science, 18*, 64–71.
Kunimoto, C., Miller, J., & Pashler, H. (2001). Confidence and accuracy of near-threshold discrimination responses. *Consciousness and Cognition, 10*, 294–340.
Mellor, D. H. (1971). *The matter of chance*. Cambridge University Press.
Mellor, D. H. (1991). *Matters of metaphysics*. Cambridge University Press.
Merikle, P. (2007). Preconscious processing. In M. Velmans & S. Schneider (Eds.), *The blackwell companion to consciousness* (pp. 512–524). Blackwell.
Overgaard, M., Fehl, K., Mouridsen, K., Bergholt, B., & Cleeremans, A. (2008). Seeing without seeing? Degraded conscious vision in a blindsight patient. *PLoS ONE, 3*(8), e3028.
Overgaard, M., Rote, J., Mouridsen, K., & Ramsøy, T. Z. (2006). Is conscious perception gradual or dichotomous? A comparison of report methodologies during a visual task. *Consciousness and Cognition, 15*, 700–708.
Persaud, N., & McLeod, P. (2008). Wagering demonstrates subconscious processing in a binary exclusion task. *Consciousness and Cognition, 17*, 565–575.
Persaud, N., McLeod, P., & Cowey, A. (2007). Post-decision wagering objectively measures awareness. *Nature Neuroscience, 10*, 257–261.
Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior, 6*, 317–327.
Reber, A. S. (1969). Transfer of syntactic structures in synthetic languages. *Journal of Experimental Psychology, 81*, 115–119.
Reber, A. S. (1989). Implicit learning and tactic knowledge. *Journal of Experimental Psychology: General, 118*, 219–235.
Reingold, E. M., & Merikle, P. M. (1993). Theory and measurement in the study of unconscious processes. In M. Davies & G. W. Humphreys (Eds.), *Consciousness* (pp. 40–57). Oxford: Blackwell.
Rosenthal, D. M. (2005). *Consciousness and mind*. Oxford: Oxford University Press.
Ruffman, T., Garnham, W., Import, A., & Connolly, D. (2001). Does eye gaze indicate implicit knowledge of false belief? Charting transitions in knowledge. *Journal of Experimental Child Psychology, 80*, 201–224.
Schurger, A., & Sher, S. (2008). Awareness, loss aversion, and post-decision wagering. *Trends in Cognitive Sciences, 12*, 209–210.
Sergent, C., & Dehaene, S. (2004). Is consciousness a gradual phenomenon? Evidence for an all-or-none bifurcation during the attentional blink. *Psychological Science, 15*, 720–729.
Seth, A. K. (2008). Post-decision wagering measures metacognitive content, not sensory consciousness. *Consciousness and Cognition, 17*, 981–983.
Seth, A. K., Baars, B. J., & Edelman, D. B. (2005). Criteria for consciousness in humans and other mammals. *Consciousness and Cognition, 14*, 119–139.
Seth, A., Dienes, Z., Cleeremans, A., Overgaard, M., & Pessoa, L. (2008). Measuring consciousness: Relating behavioural and neurophysiological approaches. *Trends in Cognitive Sciences, 12*, 314–321.
Shields, W. E., Smith, D. J., Guttmannova, K., & Washburn, D. A. (2005). Confidence judgments by humans and Rhesus monkeys. *Journal of General Psychology, 213*, 165–186.
Snodgrass, M., Bernat, E., & Shevrin, H. (2004). Unconscious perception: A model-based approach to method and evidence. *Perception and Psychophysics, 66*, 846–867.
Snodgrass, M., & Shevrin, H. (2006). Unconscious inhibition and facilitation at the objective detection threshold: Replicable and qualitatively different perceptual effects. *Cognition, 101*, 43–79.
Son, L. K., & Kornell, N. (2005). Metaconfidence judgements in Rhesus macacques: Explicit vs. implicit mechanisms. In H. S. Terrace & J. Metcalfe (Eds.), *The missing link in cognition: Origins of self-reflective consciousness* (pp. 296–320). Oxford University Press.
Tunney, R. J. (2005). Sources of confidence judgments in implicit cognition. *Psychonomic Bulletin & review, 12*, 367–373.
Tunney, R. J., & Shanks, D. R. (2003). Does opposition logic provide evidence for conscious and unconscious processes in artificial grammar learning? *Consciousness and Cognition, 12*, 201–218.
Weiskrantz, L. (1997). *Consciousness lost and found*. Oxford University Press.

Please cite this article in press as: Dienes, Z., & Seth, A. Gambling on the unconscious: A comparison of wagering and confidence ratings as measures of awareness in an artificial grammar task. *Consciousness and Cognition* (2009), doi:10.1016/j.concog.2009.09.009