Don't Bet on it! Wagering as a Measure of Awareness in Decision Making under Uncertainty

Emmanouil Konstantinidis and David R. Shanks

University College London

Author Note

Emmanouil Konstantinidis and David R. Shanks, Division of Psychology and Language Sciences, University College London, London, England.

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Correspondence concerning this article should be addressed to Emmanouil Konstantinidis, Division of Psychology and Language Sciences, University College London, 26 Bedford Way, London WC1H 0AP, England. E-mail: emmanouil.konstantinidis.09@ucl.ac.uk

Abstract

Can our decisions be guided by unconscious or implicit influences? According to the somatic marker hypothesis, emotion-based signals can guide our decisions in uncertain environments outside awareness. Post-decision wagering, in which participants make wagers on the outcomes of their decisions, has been recently proposed as an objective and sensitive measure of conscious content. In 5 experiments we employed variations of a classic decision-making assessment, the Iowa Gambling Task, in combination with wagering in order to investigate the role played by unconscious influences. We examined the validity of post-decision wagering by comparing it with alternative measures of conscious knowledge, specifically confidence ratings and quantitative questions. Consistent with a putative role for unconscious influences, in Experiments 2 and 3 we observed a lag between choice accuracy and the onset of advantageous wagering. However, the lag was eliminated by a change in the wagering payoff matrix (Experiment 2) and by a switch from a binary wager response to either a binary or a 4-point confidence response (Experiment 3), and wagering underestimated awareness compared to explicit quantitative questions (Experiments 1 & 4). Our results demonstrate the insensitivity of post-decision wagering as a direct measure of conscious knowledge and challenge the claim that implicit processes influence decision-making under uncertainty.

Keywords: Iowa Gambling Task, unconscious influences, post-decision wagering, awareness, subjective measures.

How do people make decisions and adjust their behavior in uncertain environments, and what types of knowledge control their choices? In recent years several theories have been proposed which deviate from normative models and expected utility theory, focusing more on affective and emotional processes that support decision-making under uncertainty (e.g., Dolan, 2002; Finucane, Alhakami, Slovic, & Johnson, 2000; Loewenstein, Weber, Hsee, & Welch, 2001; Mellers & McGraw, 2001; Schwarz, 2000). This work has drawn attention to the impact of affect by pointing out that automatic and rapid emotional reactions may serve as input to the decision-making process.

The somatic marker hypothesis and the Iowa Gambling Task

One popular account of the role of affect in reasoning and decision-making is the somatic marker hypothesis (SMH) proposed by Damasio (1994, 1996). Initially, the SMH was developed to explain deficits in patients with certain kinds of prefrontal brain damage (ventromedial prefrontal cortex, VMPFC) who exhibit severe decision-making impairments in social and personal domains while their cognitive and problem solving abilities remain largely unimpaired (Bechara, Damasio, Tranel, & Damasio, 2005; Saver & Damasio, 1991). Such patients also have difficulties in expressing emotional and affective information. The SMH proposes that these deficits are connected and that decision-making is regulated by neural biasing signals arising from emotion processing (see Bechara, 2004; Bechara & Damasio, 2005; Dunn, Dalgleish, & Lawrence, 2006, for reviews). These signals can be marked as either positive or negative and are linked directly to bodily states. When a negative somatic marker is associated with a possible response option, it produces an avoidance reaction; on the other hand, a positive somatic marker indicates that the response option is beneficial. In situations of uncertainty, these somatic markers can influence behavior by marking response alternatives with an emotional signal, thus providing information useful for guiding the decision process (Damasio, 1994; but see Davis, Love, & Maddox, 2009). Hence, the inability of VMPFC patients to integrate and process emotional information leads to disadvantageous decision-making which can be described as risky, prone to short-term rewards and insensitive to loss and long-term consequences (Bechara, Damasio, Damasio, & Anderson, 1994).

A major assumption regarding somatic markers is that they operate not only consciously, when someone has accessible knowledge about the possible outcomes of a choice, but also unconsciously (Bechara, Damasio, & Damasio, 2000; Bechara, Damasio, Tranel, & Damasio, 1997). Specifically, in situations of uncertainty, somatic markers can guide individuals to make advantageous decisions or avoid disadvantageous ones even when they are not explicitly aware of the quality or value of those decisions. In order to test the SMH empirically, Damasio and colleagues developed a gambling task (the Iowa Gambling Task, IGT) which attempts to simulate real-life decision-making in a laboratory setting in the way it employs uncertainty, reward, and punishment (Bechara et al., 1994; Bechara, Damasio, Damasio, & Lee, 1999).

The present research was undertaken to assess the fundamental theoretical idea, famously advocated and defended by Nisbett and Wilson (1977) that unconscious thoughts or signals can influence decision-making. Although we focus on one particular experimental task (the IGT) and one specific conception of the role of unconscious signals (the SMH), it is important to emphasize that research on the IGT provides a significant fraction of the research on the wider topic of implicit influences on decision-making. Indeed in a recent critical review, Newell and Shanks (2014) identified only 2 other sub-fields (multiple-cue probability learning, and research on the deliberation-without-attention effect) in which the same level of careful assessment of this proposal has been conducted, and concluded from their wide-ranging review that the case is far from proven. Put differently, any weakness in the evidence arising from studies employing the IGT would significantly undermine the more general claim that unconscious thoughts play a prominent role in choice behavior.

The IGT is one of the most popular and frequently used paradigms in decision-making under uncertainty and has become a standard tool for assessing decision-making deficits in a variety of clinical populations (Steingroever, Wetzels, Horstmann, Neumann, & Wagenmakers, 2013). It is a typical experience-based task where the decision-maker chooses repeatedly from a number of options without having any prior knowledge about the magnitude and distribution of the outcomes. The original structure of the task consists of 4 decks of cards (labeled A-D) from which 100 cards with different monetary payoffs are chosen without replacement. Participants are given $2000 as a loan and are instructed to pick one card at a time from any deck they choose. They must learn that turning each card carries an immediate reward: Selecting a card from the first two decks (A and B) yields $100 every trial, whereas selecting from the other two decks (C and D) yields $50. Unpredictably, the turning of some cards also carries a penalty which is large in the high reward decks A and B and small in the low reward decks C and D. Sampling from decks A and B (*bad* or *disadvantageous* decks) leads to an overall loss (a net loss of -$25 per card), whereas playing from decks C and D (*good* or *advantageous* decks) leads to an overall gain (a net gain of +$25 per card). Another feature of the task is that the probability of losses varies from deck to deck. In a selection sequence of 10 trials from deck A, the loss of $1250 is distributed over 5 cards (loss probability 0.5; punishments from $150 to $350). In deck B the punishment of $1250 occurs once, with the selection of one card (loss probability 0.1). A similar pattern of losses is reflected in the other two decks. Specifically, in deck C the $250 loss is divided across 5 cards (punishments from $25 to $75) whereas in deck D, it occurs only once (Bechara et al., 1994).

The IGT assesses decision making under uncertainty (or ambiguity), in the sense that at the outset of the task participants are ignorant of the probabilities of gains and losses (risks) associated with each deck. Experimental and neuroscience studies (e.g., Kahneman & Tversky, 1979; Lee, 2013) have yielded considerable insight into the basic mechanisms of decision making under risk (where the probabilities are known *a priori*, as in studies of description-based decision-making). Recently, research on decision-making under uncertainty has provided insightful evidence about how people behave when the probabilities and associated payoffs have to be learned by repeated sampling (i.e., experience-based decision-making) and has identified significant behavioral differences between decisions based on description and experience (the description-experience 'gap', see Erev & Barron, 2005; Hertwig, Barron, Weber, & Erev, 2004; Hertwig & Erev, 2009). In fact the IGT may be best conceptualized as a hybrid of the two, in the sense that repeated choices permit the payoff probabilities to be learned (Brand, Recknor, Grabenhorst, & Bechara, 2007). Recent work has suggested that the brain systems engaged in decision-making under risk and uncertainty may be largely overlapping (Levy, Snell, Nelson, Rustichini, & Glimcher, 2010).

Findings supporting the hypothesized role of somatic markers in decision-making come from several studies employing the IGT with VMPFC patients and normal controls whose electrodermal responses were measured via skin conductance responses (SCRs) as an index of emotional arousal or somatic markers (e.g., Bar-On, Tranel, Denburg, & Bechara, 2003; Bechara, Tranel, & Damasio, 2000; Bechara, Tranel, Damasio, & Damasio, 1996). It has been argued that the VMPFC region involved in the processing of emotion controls the modulation and generation of SCRs (Critchley, Elliott, Mathias, & Dolan, 2000). SCRs generated during the task were divided into three categories: Reward SCRs generated after selection of cards which yielded a reward, punishment SCRs after cards which carried a punishment, and anticipatory SCRs (aSCRs) prior to any deck selection. Both patients and controls showed reward and punishment SCRs. However, after a number of card selections, the control group started to generate aSCRs which were larger in anticipation of selections from the bad decks, while the lesion group did not develop these responses. The main conclusion was that failure to activate the somatic marker system leads to impaired task performance, consistent with the idea that somatic markers play an important role in guiding decision-making in normal individuals (see Damasio, Adolphs, & Damasio, 2003). Following this, Carter and Smith Pasqualini (2004) reported that the stronger the aSCRs prior to disadvantageous choices, the greater the success of participants in acquiring the advantageous strategy in the IGT (see also Guillaume et al., 2009; Oya et al., 2005).

How cognitively penetrable is the IGT?

A major issue concerning the IGT is at what stage in the task participants learn the advantageous strategy and whether this knowledge is assisted by implicit or unconscious biasing signals. In a highly influential study, Bechara et al. (1997) proposed that normal participants decide advantageously before knowing the advantageous strategy, meaning that they start to select cards from the good decks before they have conscious knowledge that those decks are the best. Tranel, Bechara, and Damasio (1999) suggested that conscious knowledge alone is insufficient to explain advantageous performance in the IGT. Similarly, Peters and Slovic (2000) used a variation of the IGT and concluded that affective processes have an important role in decision-making and can influence choice independently of conscious knowledge.

Measures of conscious knowledge in the IGT

To assess participants' knowledge about the task, Bechara et al. (1997) halted participants after 20 trials and then after every further 10 trials and asked them "Tell me all you know about what is going in the game" and "Tell me how you feel about the game". Analysis of their responses revealed that participants went through three periods before they reached the “conceptual” period where they had a firm and explicit understanding of the properties of each deck. In the “hunch” period participants developed a preference for the good over the bad decks and generated aSCRs prior to selecting from the bad decks but their verbal responses showed no confidence about this preference. The importance of Bechara et al.’s claim about the existence of unconscious signals comes from the “pre-hunch” period in which participants had experienced some losses but without any conscious insights about what was going on in the task (in the earliest period, “pre-punishment”, participants showed a preference for the bad decks before experiencing any losses from them). The key finding was that aSCRs and card selections from the good decks began in the pre-hunch period (though in fact this was not statistically significant) and were sustained throughout the task indicating that implicit learning was taking place prior to explicit understanding of the reward and punishment schedule for each deck. In other words, Bechara et al. claimed that participants behave advantageously even when their knowledge is still at the pre-hunch period, when their explicit conceptualization of which were the good and bad decks had not yet developed.

This proposal about the role of unconscious influences in guiding behavior in the IGT has been extensively criticized on the basis of weaknesses in the method that Bechara and colleagues used to assess their participants’ knowledge. For example, many studies in the implicit learning literature have shown that such broad questions as the ones they employed often fail to identify all of the conscious knowledge that participants have acquired in performing a task (Shanks, 2005; Shanks & St. John, 1994). Several criteria that a reliable measure of awareness must satisfy have been elaborated, such as reliability, relevance, immediacy, and sensitivity (Lovibond & Shanks, 2002; Newell & Shanks, 2014). Bechara et al.’s assessment (1997) does not fulfill any of these criteria. For instance, it is unlikely to be either sensitive (as participants may adopt a very conservative reporting criterion) or relevant (as participants may concentrate on reporting task features unrelated to deck value). For that reason, Maia and McClelland (2004) developed a more sensitive test of awareness in the form of a structured quantitative questionnaire. After the first 20 card selections and then after every further 10 card selections, Maia and McClelland asked their participants a number of questions in which they had to give ratings on a scale from -10 to +10 concerning how good or bad they thought each deck was and to provide justifications for their ratings. They also asked participants specific questions about the expected gains and losses associated with each deck and their level of confidence that they were aware of the best strategy to win in the game. Also, participants were asked to report which deck they would choose if they could only select cards from one of the decks for the rest of the game.

Using this assessment, Maia and McClelland (2004) found that advantageous performance on the task was accompanied by accurate reports about the values of the decks. They concluded there is no support for the claims of Bechara et al. (1997) that unconscious biases guide behavior before conscious knowledge is acquired or that the activation of unconscious somatic markers is necessary in order to perform advantageously. Instead, deck selections in the IGT are driven by conscious knowledge about the decks and by conscious strategies about how to maximize payoffs. Also, the early awareness of the goodness and badness of each deck that Maia and McClelland observed (after only 20 trials) means that aSCRs obtained on the IGT could have been generated by conscious knowledge of the deck payoffs rather than being causally involved in the decision making process (Dunn et al., 2006). Another interpretation of the high aSCRs before disadvantageous card selections lies in the reward and punishment schedule. Because the amount of money both gained and lost for each card is on average much greater for bad than for good decks, participants' aSCRs may have been higher for bad decks because they were expecting an immediate higher-magnitude reward (Tomb, Hauser, Deldin, & Caramazza, 2002). The possibility that unconscious somatic biases are activated during the task cannot be ruled out, but as Maia and

McClelland pointed out, “there is no need to invoke such biases to explain participants’ behavior: verbal reports reflect consciously accessible knowledge of the advantageous strategy more reliably and at least as early as behavior itself” (p. 16079).

Another divergence between the two studies concerns the trial at which the onset of awareness occurred. Bechara et al. (1997) reported that participants started to have some conscious knowledge on trial 50 on average (range 30-60) and the same finding was reported by Maia and McClelland (2004) in their replication using Bechara et al.’s assessment. However, using the more detailed quantitative questions described above, Maia and McClelland’s participants were classified as aware of the difference between good and bad decks even after the first 20 trials. This divergence suggests that the measure employed by Maia and McClelland is considerably more sensitive in revealing the conscious knowledge that participants acquired.

Similar findings have been reported from other studies which employed quantitative and focused questions (e.g., Bowman, Evans, & Turnbull, 2005; Cella, Dymond, Cooper, & Turnbull, 2007; Evans, Bowman, & Turnbull, 2005; Wagar & Dixon, 2006). Bowman et al. (2005) assessed participants’ knowledge by asking them to rate each deck in terms of how good or bad they felt it was. After the first 20 trials, participants showed substantial awareness of which decks were good and bad and their awareness discriminated the good from bad decks better than their behavioral performance did, replicating the results of Maia and McClelland (2004).

Post-decision wagering

In order to avoid some of the complications associated with verbal reports, Persaud, McLeod, and Cowey (2007) developed a novel non-verbal method of assessing awareness in the IGT in which participants are required to place wagers after their card selections. Persaud et al. characterized post-decision wagering as an objective and direct measure of awareness.

When a participant maximizes her earnings through advantageous wagering (that is, bets high after a correct decision and low after an incorrect one), this is taken to indicate conscious knowledge about the task.

In Persaud et al.’s (2007) variation of the IGT, participants were asked to make a wager of £10 or £20 after each deck selection. The amount of reward, or of reward and punishment, was expressed as a multiple of the chosen wager. The reward and punishment schedule of each deck was modified in order to be dependent on wagering. Selections from decks A and B (bad decks) yielded a win of two times the wager whereas selections from decks C and D (good decks) returned the amount of the wager. The frequency of losses was identical to the structure of the original IGT whereas the magnitude was adjusted to reflect the ratio of losses to wins of the original IGT. The net outcome of choosing from the bad decks was a loss of 5 times the average wager per 10 cards, and the net outcome from the good decks was a gain of 5 times the average wager per 10 cards. Thus, the net outcome was either a win of £75 (good decks) or a loss of £75 (bad decks) [((20 + 10) / 2) × 5] per 10 cards if participants randomly allocated their wagers (50% high, 50% low).

Persaud et al. (2007) investigated the influence of different modes of questioning in parallel with deck selections and wagering in three different groups. The first group was asked only to place a wager, whereas the second and third groups were also given the verbal assessments used by Bechara et al. (1997) and Maia and McClelland (2004), respectively. Persaud et al. measured on which trial good deck selection and advantageous wagering began and conjectured that if a significant difference (lag) between these measures emerged, with deck selections revealing a preference for good decks before advantageous wagering emerged, this would indicate an unconscious influence on decision making. In the first group, good deck selection began on trial 40 and advantageous wagering on trial 70. The difference between these was statistically significant and indicated that participants showed a preference for the good decks while failing to maximize their winnings by advantageous wagering. The same pattern was observed in the second group in which participants were asked the open-ended questions used by Bechara et al. Good deck selection started on trial 46 and advantageous wagering on trial 76. However, using the quantitative questions of Maia and McClelland, there was an effect on wagering even though performance on the task in terms of deck selections was similar to the other two groups. Specifically, good selection began on trial 36 and advantageous wagering at almost the same time (trial 38).

Persaud et al. (2007) interpreted these findings as demonstrating that the assessment method can affect the knowledge that participants acquire during the IGT. While performance (selecting the good decks) was unaffected, participants gained earlier insight (as measured by wagering) about the reward and punishment schedule and the quality of each deck when they were concurrently asked more specific quantitative questions about the nature of the game. Indeed the onset of advantageous wagering was brought forward by over 30 trials in the group that was periodically asked the Maia and McClelland quantitative questions. Persaud et al. proposed that Maia and McClelland's (2004) assessment method was intrusive and altered participants' awareness and that performance on the IGT is primarily affected by unconscious processes which are masked if the measure of awareness itself makes participants aware of the nature of the task (see also Koch & Preuschoff, 2007; Reimann & Bechara, 2010; Wang, Krajbich, Adolphs, & Tsuchiya, 2012).

Persaud et al. (2007) stated that "Simply asking people might seem a straightforward method, but they may deny awareness if the question asked does not relate to the method they think they used to reach the decision" (p. 257) which is a reasonable critique of the open-ended questions used by Bechara et al. (1997). However, an intriguing issue that arises from their own results is to examine the trial on which participants first demonstrated awareness of the reward and punishment schedule. When no questions were asked or when participants' awareness was assessed by open-ended questions, advantageous wagering – putatively a measure of awareness – appeared quite late in the task (not before trial 70). This pattern, which Persaud et al. did no comment on, is strikingly inconsistent with the studies described above which showed that higher awareness ratings were given for the good decks even in the first 20 trials. Although some minor property of the way they implemented the task or of their participants might have induced this late sensitivity, it raises the important possibility that post-decision wagering is not as sensitive and direct as Persaud et al. claimed.

Criticisms of post-decision wagering

Although post-decision wagering seems a well-grounded method, it has been the subject of a number of methodological criticisms. First of all, the dichotomous nature of post-decision wagering seems to presuppose that conscious experience is dichotomous as well (see Overgaard, Rote, Mouridsen, & Ramsoy, 2006; Sandberg, Timmermans, Overgaard, & Cleeremans, 2010). If conscious experience does not have this binary character then it is difficult to ascertain when a participant is aware, as a low wager may not imply absence of awareness (Wierzchon, Asanowicz, Paulewicz, & Cleeremans, 2012).

Another issue is the influence of loss aversion in wagering strategies. According to prospect theory, humans have an asymmetric utility function; for example, the prospect of losing $5 has greater subjective magnitude than that of winning the same amount of money (Kahneman & Tversky, 1979; Schurger & Sher, 2008). Empirical studies have shown that losses are evaluated roughly twice as much as gains (e.g., De Martino, Camerer, & Adolphs, 2010; Thaler, Tversky, Kahneman, & Schwartz, 1997; Tom, Fox, Trepel, & Poldrack, 2007). Behavioral measures of awareness, such as post-decision wagering, require participants to place a criterion on their subjective evidence scale about whether to wager high or low. Hence, any response criterion may be modulated or affected by cognitive biases such as loss aversion (Seth, Dienes, Cleeremans, Overgaard, & Pessoa, 2008). Specifically, the individual could place a low wager in order to minimize loss even though she has some confidence in her decision. In an artificial grammar study, Dienes and Seth (2010) employed two different measures of conscious knowledge, confidence ratings and post-decision wagering. They found that wagering was affected by loss aversion and that confidence ratings comprised a more sensitive measure of awareness.

A final issue regarding post-decision wagering is that the optimal strategy for wagering in the experiments of Persaud et al. (2007) is, paradoxically, always to wager high, as this strategy will give the same outcome if good vs. bad deck discrimination is at chance but will increase winnings if it is greater than chance. In this sense wagering high can be said to be a weakly dominant strategy with Persaud et al.'s payoff matrix as it is either no worse than wagering low, or better. A rational participant would always wager high, regardless of her knowledge about the task (Clifford, Arabzadeh, & Harris, 2008). (Note that for the sake of simplicity we will continue to define and measure advantageous wagering as wagering high on good deck selections and low on bad ones). This leads to the question: "How can a failure of a subject to wager optimally be a measure of lack of awareness of the sensory evidence when the optimal strategy is independent of that evidence?" (Clifford et al., 2008, p. 56). Clifford et al. proposed a solution to this by modifying the original payoff matrix used by Persaud et al. (Table 1).

System 1 vs. System 2, Conscious vs. Unconscious, Intuition vs. Deliberation

The question whether behavior and decision-making can be influenced by unconscious "gut feelings" and "intuitive processes" has attracted considerable attention within psychological science. The different formulations of this distinction (e.g., System 1 vs. System 2, intuition vs. deliberation) have different functional attributes and procedural features but also share some common characteristics. For example, System 1 is unconscious, associative, effortless, and fast whereas System 2 is conscious, deliberative, and rulegoverned (see Kahneman, 2011). An important feature of System 1 is its reliance on affective information or signals (Slovic, Finucane, Peters, & MacGregor, 2002). Hence somatic markers (or emotional/affective biasing signals) can be seen as manifestations of System 1, guiding people to make advantageous decisions in situations of uncertainty and outside of awareness. Thus the main assumptions of the SMH fit readily within this dichotomy of reasoning systems.

In the present work, we examine the claim of different reasoning and learning systems in the context of one of the most frequently used decision-making tasks, the IGT. In particular, we investigate whether people have relevant conscious insight when they make advantageous decisions. The present experiments focus on the outcome of the process that leads participants to make good decisions and ask whether this outcome is consciously accessible or not.

Overview

Developing valid and sensitive non-verbal methods of assessing awareness is an important goal and post-decision wagering holds much promise. It has been used, for example, to study decision-making and awareness in nonhumans (Kornell, Son, & Terrace, 2007; Middlebrooks & Sommer, 2011, 2012) and children (e.g., Miller, Brownell, & Zukier, 1977; Ruffman, Garnham, Import, & Connolly, 2001) where traditional confidence scales can be difficult to use. Also, it has been extensively employed as a probe of conscious knowledge in several areas of experimental psychology such as perceptual decision-making and subliminal perception (e.g., Koriat, 2011; Nieuwenhuis & de Kleijn, 2011; Persaud et al., 2011; Persaud & McLeod, 2008; Sandberg, Bibby, Timmermans, Cleeremans, & Overgaard, 2011; Sandberg et al., 2010; Weiss & Scharlau, 2011; Zizlsperger, Sauvigny, & Haarmeier, 2012), implicit learning (e.g., Haider, Eichler, & Lange, 2011; Mealor & Dienes, 2012;

Wierzchon et al., 2012) and value-based decision-making (e.g., Lueddeke & Higham, 2011; Wang et al., 2012).

The five experiments reported here permit a more detailed evaluation of post-decision wagering as a measure of awareness in decision-making under uncertainty. The current work uses the IGT (and variations) as the main decision-making paradigm for three reasons: first, the IGT is probably the most frequently used task to assess decision-making deficits. As such, our work will shed more light into the processes that drive performance on the task and help identify key elements of decision-making under uncertainty, namely whether participants have conscious knowledge when they make advantageous decisions. Second, the IGT is a typical experience-based task, indicating that this work could potentially benefit a large area within decision-making. Third, the IGT has been the main assessment to test and develop the SMH, a popular account of the processes relating reasoning, decision-making, and affect.

This work has two major aims. We compare wagering with confidence ratings and participants' quantitative numerical reports, mindful of the possibility that quantitative questioning might reflexively influence the development of awareness of the deck values. We also compare different versions of wagering which are identical in all respects except with regard to the payoff matrix, so as to determine whether the results obtained by Persaud et al. (2007) were due to an idiosyncrasy of the matrix they employed (such as the weak dominance noted above) and to ask whether the evidence they obtained for unconscious influences in decision-making is robust.

Experiment 1

Experiment 1 included two groups in an attempt to reproduce the key findings reported by Persaud et al. (2007). Both groups performed the IGT and made post-decision wagers. In the questionnaire group participants were also regularly asked a subset of Maia and McClelland's (2004) quantitative questions, while those in the control group were not.

Comparisons between these groups allow a number of issues to be addressed: first, in the control group, is there evidence that deck selections begin to discriminate good from bad decks before the trial at which advantageous wagering first occurs? This is the key piece of evidence for an unconscious influence on decision-making. Secondly, does quantitative questioning bring forward the point at which advantageous wagering occurs, as Persaud et al. suggested? Thirdly, what is the comparison between wagering and quantitative judgments in the questionnaire group? Although they included such a group, Persaud et al. did not report the quantitative judgments their participants made. Even if making these judgments has the effect of focusing participants' attention on the task and rendering them more rapidly aware of the task structure (and hence improves wagering), it is still of considerable interest to examine such data. Importantly, we can ask whether the quantitative assessments participants make at their first assessment (trial 20) – when questioning cannot have had any effect on task awareness – reveals awareness which is undetected by the wagering measure.

Experiment 1 thus aimed to replicate the design and methodology employed by Persaud et al. (2007). One difference between our experiment and Persaud et al.'s lies in the format of the IGT. We used a computerized version of the IGT whereas Persaud et al. used a classic manual format (see Bechara et al., 1994). Previous studies observed no differences in the pattern of deck selections between format types, however (Bechara, Tranel, et al., 2000; Bowman et al., 2005). Table 2 lists the task features that we varied across the experiments reported here.

Method

Participants. Thirty volunteers (20 females) between the ages of 19 and 30 years (*M* = 22.66, *SD* = 2.96) were recruited from the University College London subject pool. All participants received £3 for their participation. Across experiments, the sample sizes were chosen in order to match or somewhat exceed those in Persaud et al.'s (2007) original study, 12 per group. In Experiments 1, 2, 4A, and 4B the sample sizes were between 15-30 per group (15, 30, 19, 21, respectively). The only exception was Experiment 3, in which we collected data from 38-40 participants per group. These participants were UCL undergraduate psychology students participating in a compulsory laboratory class.

Design. Participants were randomly assigned to one of two groups (no questioning [control], quantitative questioning [questionnaire]). The control group made a high or a low wager following each deck choice whereas the questionnaire group, in addition to wagering, were asked a subset of the Maia and McClelland (2004) questions every 20 trials. In the original study, the questionnaire was given to participants every 10 trials after the first administration on trial 20. We reduced the frequency of administering the questionnaire to limit fatigue.

Task. A computerized variant of the IGT was employed. There were four decks of cards with labels A, B, C, and D. The rewards and punishments were the same as in Persaud et al. (2007) and these were dependent on the quality of the deck (Good or Bad) and the wager (High: £20 or Low: £10). Specifically, selecting a card from the bad decks (A and B) yielded a win of two times (2 ×) the wager (High: £40, Low: £20) whereas selecting a card from the good decks (C and D) returned the wagered amount (1 ×) (High: £20, Low: £10). Also, some trials carried a punishment; the distribution and frequency of the punishments were as for the original IGT whereas the magnitude was adjusted to reflect the ratio of loss to win of the original IGT (see Appendix A for the reward and punishment schedule).

Participants in both groups were given an initial endowment of £400 of play money and were asked to maximize their earnings. The task comprised 100 card selections. After each card selection, a frame appeared on the screen with two alternative choices, “High (£20)” and “Low (£10)”, allowing participants to place a wager on their card selection. Along with wagering the questionnaire group was administered a modified version of Maia and

McClelland’s (2004) questionnaire (see Appendix B). The qualitative parts of the questionnaire were omitted and it was administered every 20 trials. Participants were asked to provide ratings of the “goodness” of each deck, to report or calculate amounts of money related to the decks’ payoffs, and to indicate which deck they would select cards from for the rest of the task if they could only choose from one deck.

Instructions were presented on the screen before the experiment started. At the top of the display was a green bar that expanded or contracted according to the amount of money won or lost after each deck selection and wager. Every time a participant clicked on a deck to pick a card, the deck was highlighted and the wagering frame appeared on the screen. After the wagering selection, the face of that card appeared on the top of the deck showing the amount of money behind the card and a message was displayed on the screen indicating the amount of money won or lost. Once the money had been added or subtracted, the face of the card disappeared and the participant could select another card.

Procedure. Participants sat in front of a PC display. They were then asked to read the on-screen instructions about the task. In brief, participants were told that the game was about learning to gamble on card selections, that all of the cards would yield some money but some would lose money, that their objective was to win as much as money as possible, and that they were free to switch from one deck to another at any time. Additionally, participants were presented with instructions about wagering. Specifically, they were told that if they were confident that their choice would give them some net winnings, then they should wager high, otherwise, they should make a low wager. The questionnaire group was presented with instructions about the quantitative questions. Each session ended after 100 trials.

Results

Choice and wagering. Advantageous wagering was defined as either a high wager after choosing a good deck or a low wager after choosing a bad deck. Our analyses employed the average proportion of good deck selections (choice) and advantageous wagers (wagering) across subjects over successive blocks of 10 trials to investigate any differences between the two groups (control, questionnaire) and to locate the onset of learning and awareness (see Figure 1).

The onset of deck discrimination, as revealed by the first block in which choice of the good decks was significantly above chance (0.50), was at block 4 for both conditions (Control: M = 0.63, t(14) = 3.25, p = .006, d = 0.84, Questionnaire: M = 0.70, t(14) = 5.29, p <.001, d = 1.37). Advantageous wagering exceeded chance level (0.50) at the same time as choice, also in block 4 (Control: M = 0.63, t(14) = 3.08, p = .008, d = 0.80, Questionnaire: M = 0.66, t(14) = 3.43, p =.004, d = 0.89). These results indicate that there was no advancement in the onset of advantageous wagering in the quantitative questioning group who made explicit judgments about the deck payoffs.

Two separate mixed ANOVAs were performed on the proportion of good deck selections and advantageous wagers across blocks of 10 trials. It is important to note that even though they use the same scale, the two measures cannot be compared directly because advantageous wagering is dependent on the first-order decision (e.g., deck selection) and this creates the possibility of functional differences between the measurement scales. For example, if a participant always chooses a good deck (with the proportion of good deck selections therefore being 1.0), but decides to make both high and low wagers because she is more confident on some trials than others, then advantageous wagering cannot attain a value of 1.0. Its maximum value under such circumstances would be equal to the proportion of high wagers. Like Persaud et al. (2007), our contrast between deck selection and wagering is therefore an indirect one, based on estimating the trial block at which each reaches a level significantly above chance. This contrast is likely, if anything, to be biased in favor of obtaining evidence of learning without awareness. Both measures could be numerically above chance, but deck selection might be significantly so and wagering not (it might be a noisier measure, for instance).

A 2 (group [control, questionnaire]; between) × 10 (block: 10 trials each; within) mixed ANOVA was performed to assess group differences on good deck selections. For the main effect of block, polynomial contrasts were also applied. The analysis revealed a significant main effect of block, $F(9, 252) = 26.80$, $MSE = 3.00$, $p < .001$, $\eta_G^2 = 0.39$ (for generalized eta squared, η_G^2, see Bakeman, 2005), indicating that participants learned about the quality of each deck as there was a tendency for choice to increase across time (significant linear and quadratic effects, $p<.001$). The main effect of group did not reach significance, $F(1, 28) = 0.92$, $MSE = 10.94$, $p = .35$, $\eta_G^2 = 0.01$, and the interaction between group and block was not significant, $F(9, 252) = 0.39$, $MSE = 3.00$, $p = .94$, $\eta_G^2 = 0.01$, suggesting that the mean proportion of good deck selections across blocks was similar in the two conditions. This finding is in accordance with Persaud et al.'s (2007) results: in their study more detailed questioning did not affect participants' deck-selection strategies. In other words, when awareness is probed by more "invasive" methods, no effect is observed in the application of this knowledge to decision-making behavior.

Analysis of the proportion of advantageous wagers revealed a similar pattern of results. Again, the main effect of group was not significant, $F(1, 28) < 1$, $MSE = 13.12$, $p = .86$. Participants were able to maximize their winnings as the proportion of advantageous wagers increased across blocks, $F(9, 252) = 19.35$, $MSE = 3.44$, $p < .001$, $\eta_G^2 = 0.32$. The interaction between group and block was not significant, $F(9, 252) = 0.46$, $MSE = 3.44$, $p = .90$, $\eta_G^2 = 0.01$.

In the Supplemental Materials we present analyses of participants' wagering behavior in terms of signal detection theory for this and all subsequent experiments. These analyses confirm the key conclusions using a method which allows sensitivity (the ability to use wagering responses to discriminate between good and bad decks) and bias (preference for wagering high or low) to be separately determined.

These results indicate that participants favored the good decks and became gradually capable of maximizing their winnings by placing appropriate wagers. The estimated onsets of good deck selections are consistent with those reported by Persaud et al. (2007) (also see, Turnbull, Evans, Bunce, Carzolio, & O'Connor, 2005; Wagar & Dixon, 2006), namely on trials 40 and 36 (block 4) for their control and questionnaire groups, respectively. The key result though is that advantageous wagering developed according to approximately the same time-course as choice behavior. The extra requirement to rate the quality of the decks and answer questions about the payoffs did not affect participants' decision-making or wagering strategies. Since choice and wagering displayed similar patterns in both groups there is no evidence of a dissociation between learning and awareness of the optimal strategy, assuming that wagering is indeed a valid index of awareness. The simultaneous onset of awareness in the two groups also contradicts the main claim of Persaud et al. (2007) about learning without awareness in the IGT. Specifically, Persaud et al. reported that in their control group, where no quantitative questions were asked, advantageous wagering lagged behind deck selections whereas this was not the case in their quantitative questioning group. This pattern was not observed here[1].

Questionnaire. Participants' knowledge regarding the advantageous strategy in the questionnaire group was explored. Two of the measures reflect knowledge about the general quality of each deck and the remaining two about the actual payoffs. For questions 1 and 4 (see Appendix B) if a participant gives the highest rating to one of the two best decks and selects one of the two best decks to pick cards until the end of the experiment, that means the participant possesses accurate knowledge about the task. In the same manner, when the highest reported (Question 2.1) and calculated net (Questions 2.2, 2.3 and 2.4) is attributed to one of the best decks, this indicates high levels of awareness. The calculated net (CN) for each participant, deck, and question period is obtained using the following equation: CN= Q2.2 + (Q2.3 / 10) × Q2.4.

Figure 1B shows the proportion of participants whose answers favored the good decks on each of the questionnaire measures. Participants whose verbal responses did not discriminate between good and bad decks (i.e., they give the same ratings or the same reported net for all decks) do not count towards this proportion. Inspection of the figure shows that participants exhibited substantial knowledge about the quality of each deck even in the first assessment period (trial 20). Not only did they rate the good decks higher than the bad decks, but also they had a firm basis for such an attribution as revealed by their reported and calculated net payoffs. Table 3 shows the mean deck ratings (-10 very bad, +10 very good) for each deck and the proportion of selections throughout the task for both groups. The results show a clear trend, that is the more positive the rating for a deck, the more likely the deck was to be selected. This correlation between ratings and selections adds further support to the view that decision strategies in the IGT develop in parallel with explicit knowledge.

The use of the questionnaire allowed us to explore differences between the two measures (i.e., post-decision wagering and questionnaire) in terms of how sensitive each is in assessing participants' awareness. It is important to check whether the quantitative questions reveal more knowledge about the task than wagering in the first assessment (trial 20). However, the two measures are not directly comparable due to the fact that the questionnaire was administered once at trial 20 whereas participants placed wagers after each deck selection. To overcome this problem we classified each participant as aware or unaware based on the average proportion of advantageous wagers placed across trials 16-25. If the average was equal to or greater than .5, then participants were identified as aware of the advantageous strategy. The proportion of participants classified as aware by the wagering measure was then compared against the proportion of participants who favored one of the two good decks in Question 4 (i.e., deck-selected measure). We used the deck-selected measure because it requires only one response and is therefore similar to wagering. To see whether the two proportions were significantly different (deck-selected: 0.67, wagering: 0.33) we used the McNemar test for dependent proportions (see Agresti, 2002; Wild & Seber, 1993) which was found to be non-significant, $\chi^2(1) = 2.78$, $p = .096$, possibly due to the small sample size (N=15). Nevertheless, the numerical difference suggests that wagering underestimates participants' acquired knowledge possibly due to the effects of biases in participants' wagering strategies.

Discussion

We draw three principal conclusions from Experiment 1. First, under the conditions tested here awareness as measured by wagering tracked deck selections quite closely. We found no indication that wagering lagged behind the selection of good decks, with both measures becoming reliably better than chance fairly early in the task, between trials 30 and 40. Secondly, the results of the explicit questions revealed that wagering, if anything, underestimates task insight. As early as trial 20, the majority of participants were able to give accurate reports about the quality of the different decks. Thirdly, there was no evidence that eliciting explicit reports in the questionnaire group altered participants' wagering strategy. Persaud et al. (2007) did report such a bias, but it was not observed here. Regardless of whether they explicitly reported their task knowledge, participants began to wager advantageously in block 4 (and this is about the same point at which they began to reliably select the better decks).

Experiment 2

Experiment 1 obtained no evidence of a dissociation between learning and awareness. Experiment 2 further examines the utility of wagering as a valid alternative to verbal reports for assessing awareness by applying two modifications to Persaud et al.'s (2007) procedure. First, the original reward and punishment schedule of the IGT was used, and secondly we tested the modified pay-off matrix proposed by Clifford et al. (2008). As noted earlier, the pay-off matrix used by Persaud et al. encourages rational participants to employ the weakly-dominant strategy of making high wagers all the time, irrespective of the knowledge they possess about the decks (see Table 1). The modified version of the pay-off matrix, in contrast, encourages participants to wager low under uncertainty and to wager high when they have acquired some knowledge about the decks.

Specifically, in the modified matrix participants are discouraged from wagering high until they feel confident that their decision is a good one. When discriminative knowledge about the decks is absent or low, it is advantageous to wager low. This can be shown by the expected payoff from wagering low which is +1/2 [(+2 -1)/2] compared to 0 [(+5-5)/2] from wagering high. However, when deck discrimination is better than chance, it is more rewarding to wager high due to a larger payoff with a good/high combination (+5) than a good/low one (+2). Based on this matrix a rational participant (i.e., a participant who seeks to maximize gains) would start to wager high only when her deck discrimination (probability of selecting a good deck is) 4/7 or .57. The latter can be computed from the differential loss of wagering on a bad decision (5-1=4) divided by the sum of the differential loss and the differential gain of wagering on a good decision (5-2=3) (Clifford et al., 2008).

Experiment 2 therefore allows us to ask two main questions. First, we have another opportunity to examine whether awareness as measured by wagering lags behind deck selection. Secondly, we can ask whether the modified payoff matrix locates the onset of awareness at an earlier point than the original matrix. Given that Experiment 1 suggested that wagering (under the original matrix) locates the onset of awareness far too late (in comparison to numerical reports on the values of the decks), it is possible that the modified matrix will yield a more appropriate, earlier, estimate.

Method

Participants. Sixty healthy volunteers participated (28 females, age *M* = 22.32, *SD* = 3.02). Thirty-five participants were recruited via the subject pool and the rest were undergraduate students who received course credit for participating. Participants were randomly assigned to the two conditions.

Design. The simple-wagering group participated in a replication of Persaud et al.'s (2007) IGT task with wagering. The differences between Persaud et al.'s study and this experiment are that we employed the original reward and punishment schedule of the IGT, and the wagers were divided by a factor of 10 (see Table 2). The modified-wagering group was administered the IGT with wagering but using the pay-off matrix proposed by Clifford et al. (2008) (see Table 1).

Task. The reward and punishment schedule used in this study was the same as in the original IGT. After selecting a card from decks A and B participants won £100 whereas on decks C and D they won £50. However, on some trials, there was a punishment which was larger on decks A and B compared to decks C and D. On deck A, 50% of the trials carried a punishment (varying from £150 to £350) leading to an overall loss of £250 every 10 trials. On deck B, the net outcome was the same as in deck A (-£25 per card) but there was one large loss (£1250) every 10 trials. The same pattern was present on decks C and D; on deck C, 5 out of 10 trials had a punishment (from £25 to £75) leading to an overall gain of £250 (+£25 per card) whereas on deck D, there was one loss (£250) every 10 trials.

After each card selection in the simple wagering group, a new frame appeared on the screen with two alternative choices, “High (£2)” and “Low (£1)”, allowing participants to place a wager on their card selection. The amount behind the card was multiplied either by 2 or 1 according to wager selection. In the modified wagering group, the procedure was the same, except that the wagers were not expressed as amounts of money but simply as “High” and “Low”. This is because the final amount of money won or lost after each card selection was multiplied by the appropriate weights in the modified pay-off matrix.

The task again comprised 100 card selections. Because there were only 40 cards in each deck, it was possible to run out of cards from a given deck (as in the original IGT – this was not the case in Experiment 1). When this happened, a message appeared on the screen instructing participants to stop choosing from that deck and to continue selecting from the remaining decks.

Procedure. The procedure of Experiment 2 was identical to that of Experiment 1.

Results

Choice and Wagering. The method for identifying the onset of good deck selections and advantageous wagering was the same as in Experiment 1 (see Figures 2A and 2B). Good deck selection commenced on block 5 for the simple wagering group, $M = 0.63$, $t(29) = 3.20$, $p = .003$, $d = 0.58$, but on block 4 for the modified wagering group, $M = 0.68$, $t(29) = 4.81$, $p < .001$, $d = 0.88$. There hence seems to be a small difference in the onset of learning between the two groups. Additionally, a difference was observed regarding the onset of advantageous wagering. Specifically, in the simple wagering group awareness arose relatively late in the task, on block 7, $M = 0.61$, $t(29) = 2.82$, $p = .008$, $d = 0.51$, whereas participants started to place appropriate wagers on block 4 in the modified wagering group, $M = 0.69$, $t(29) = 5.48$, $p < .001$, $d = 1.00$.

A 2 (group [simple wagering, modified wagering]; between) × 10 (block: 10 trials each; within) mixed ANOVA on the proportion of good deck selections revealed a non-significant main effect of group, $F(1, 58) = 0.22$, $MSE = 5.24$, $p = .65$. There was a significant main effect of block, $F(7.19, 416.22) = 32.59$, $MSE = 4.22$, $p < .001$, $\eta_G^2 = 0.33$

(significant linear and quadratic trends). The analysis also revealed a significant group × block interaction, $F(7.19, 416.22) = 2.18$, $MSE = 4.22$, $p = .022$, $\eta_G^2 = 0.03$ (Greenhouse-Geisser correction). Simple effects analyses showed a significant difference on block 4 ($F(1, 58) = 14.86$, $MSE = 3.77$, $p < .001$) which is consistent with the difference reported above in the onset of good deck selections between the two groups.

A similar analysis was performed on the proportion of advantageous wagers. The main effect of group was significant, $F(1, 58) = 4.15$, $MSE = 12.02$, $p = .046$, $\eta_G^2 = 0.02$, as participants in the modified wagering group demonstrated higher proportions of advantageous wagers across blocks. The main effect of block was significant, $F(9, 522) = 16.88$, $MSE = 3.65$, $p < .001$, $\eta_G^2 = 0.18$. The difference between the two groups in awareness was further supported by a significant group × block interaction, $F(9, 522) = 3.36$, $MSE = 3.65$, $p < .001$, $\eta_G^2 = 0.04$, with reliable differences in blocks 4, 5, 6, and 7 (simple effects comparisons, $p < .05$), reflecting the later onset of awareness in the simple wagering group. These results demonstrate that awareness lagged behind deck selections in the simple wagering group which is in accordance with the dissociation between the two measures observed by Persaud et al. (2007). In addition it appears that asymmetric weights in the pay-off matrix of the modified wagering group helped participants to perform advantageously earlier in the task.

Discussion

Whereas Experiment 1 revealed no lag between deck selection and awareness – the latter measured by wagering – the present experiment did reveal such a lag in the simple wagering group, of approximately 2 blocks of trials. In this group, advantageous deck selections became reliable at block 5 whereas wagering only became significantly better than chance in block 7. Presumably one of the minor procedural changes between Experiment 1 and Experiment 2 (see Table 2) led to the difference in findings. In addition, the difference in findings cannot be ascribed to low statistical power to detect the effect found in Experiment 1. Specifically, the question is whether Experiment 2 (simple wagering group) had adequate power to detect an awareness effect at block 5 (which is where good selection started) of the magnitude seen in Experiment 1 (control group) at block 4 (which is where awareness emerged in that group; *d* = 0.8). The relevant power figure is 0.82 which indicates adequate statistical power to detect the awareness effect of Experiment 1 (control group).

The reward and punishment schedule used in Experiment 2 was the same as in the original IGT. In fact, the pattern of deck selections was slightly different compared to Experiment 1 (compare Table 3 and Figures 2C and 2D). Deck B was selected more often which is in accordance with previous studies that used the original IGT and evaluated the perceived "badness" of deck B (Lin, Chiu, Lee, & Hsieh, 2007). Examination of choice behavior in Experiment 1 (Table 3) and Persaud et al.'s (2007) study reveals a different pattern, which is not present in studies with the original IGT payoff schedule. Put differently, the reward and punishment schedule used in Experiment 1 turns out to be easier to learn than that of the original IGT in Experiment 2. Fernie and Tunney (2008) identified difficulties with the manipulations of the reward and punishment schedule of the IGT; because wins, loss probability and magnitude, and overall expected values are all confounded with each other it is difficult to ascertain which aspect of the schedule has a bigger effect on choice behavior.

Although the lag observed in the simple wagering group (which replicates what Persaud et al., 2007, found) might be taken as evidence that advantageous deck selection is driven initially by unconscious influences, the results from the modified wagering group suggest caution in drawing such a conclusion, because a relatively small change in the payoff matrix brought wagering back into line with deck selections (and led participants to select from the good decks slightly earlier than those exposed to the original matrix). Why might this have happened? One hypothesis is that it arises because the original payoff matrix discourages participants from thinking carefully about the wagers they place, especially before they have learned which are the best decks. There is a possibility that Persaud et al.'s matrix led participants to believe that, prior to learning, wagering had no overall effect on their winnings. As noted previously, it is indeed the case that with a symmetric matrix and random deck selection, it makes no difference how the participant wagers. Participants may therefore have stopped thinking carefully about their wagers. As the optimal weakly dominant strategy using the original matrix is always to wager high (Clifford et al., 2008), this means that the payoffs are independent of the wagers, and thus participants may have believed that their wagers were irrelevant. When they started to learn about the quality of each deck and discovered that their wagers might be relevant to the encountered payoffs, it may then have taken them longer to implement this new knowledge into their wagering strategy, leading to an apparent late onset of awareness. In contrast, the asymmetric payoffs of the modified matrix encourage participants to believe that it matters whether they wager high or low, even before they start to choose the good decks. In other words, the original pay-off matrix did not guide participants to express their knowledge as their wagering choices were random and not consistent with their deck selections.

Experiment 3

The purpose of this experiment was to compare post-decision wagering with confidence ratings, the simplest and most commonly used measure of awareness (for some examples see Dienes, Altmann, Kwan, & Goode, 1995; Fleming, Weil, Nagy, Dolan, & Rees, 2010; Szczepanowski, Traczyk, Wierzchon, & Cleeremans, 2013; Tunney & Shanks, 2003). Confidence ratings are metacognitive reports about having performed a judgment or discrimination accurately (e.g., perception of a subliminal visual stimulus) or having selected the best from a set of alternatives (e.g., selection of a good deck in the IGT). Confidence ratings can be expressed in a binary way such as "not confident" and "very confident" (different labels have been employed such as “guessing” and “knowing”) or on a continuous Likert-like scale.

In this experiment we used a 2-point confidence scale in order to make a direct comparison with binary wagering, and also a 4-point scale to gain deeper insights into the confidence-performance relationship.

Method

Participants. There were 118 participants in the experiment (97 females, age *M*=18.73, *SD*=0.90), all of whom were psychology undergraduate students at University College London who took part in fulfillment of a course requirement. The 6 best performers on the task were awarded £15 each.

Design. The experiment consisted of three different conditions: binary wagering (*N*=40), binary confidence ratings (*N*=40) and 4-point confidence ratings (*N*=38). Participants were randomly assigned to one of the three conditions.

Task. The original IGT payoff schedule was used across conditions (as in Experiment 2). After each card selection, participants were asked to indicate their awareness of the deck payoffs using wagering or confidence ratings. In the binary wagering condition, participants had to place a wager, High (£2) or Low (£1), which multiplied the payoffs associated with each deck and trial (this condition was identical to the simple wagering condition of Experiment 2). In the binary confidence condition, participants were asked to express their confidence in having selected a good deck using the descriptions 1 = “I am not confident” and 2 = “I am very confident”. The descriptions for the 4-point confidence scale were 1 = “I am guessing”, 2 = “I am not confident”, 3 = “I am quite confident”, and 4 = “I am very confident”.

Procedure. The procedure was identical to that of previous experiments, with the exception that a different set of instructions was presented for the confidence ratings measure.

Results

Choice and Awareness. Evidence of conscious knowledge regarding the optimal strategy in the binary wagering condition was obtained using advantageous wagering (a high wager after a good deck and a low wager after a bad deck). The same principle was applied to the confidence ratings conditions so that the combinations good deck/high confidence and bad deck/low confidence were taken to indicate conscious knowledge. In this stage of the analysis the 4-point scale was dichotomized with confidence levels 1 and 2 collapsed to signify *low confidence* and 3 and 4 collapsed to give *high confidence*. We then identified the onset of choice and awareness as the first block at which performance was significantly above chance (0.5) for each of the three conditions (see Figure 3). With this method, good deck selections exceeded the chance level on block 5 for the binary confidence ratings, M = 0.60; $t(39) = 3.00$, $p = .004$, $d = 0.48$, and wagering groups, M = 0.60; $t(39) = 2.82$, $p = .007$, $d = 0.45$, and block 6 for the 4-point confidence group, M = 0.62; $t(37) = 3.73$, $p < .001$, d = 0.61. These results indicate slightly later (about 1 block) deck discrimination than in previous experiments.

Regarding conscious knowledge of the deck values, confidence ratings significantly exceeded chance at the same time as or earlier than choice in the confidence rating groups, namely at block 5 in both cases (2pts scale: M = 0.62; $t(39) = 3.89$, $p < .001$, d = 0.62, 4pts scale: M = 0.58; $t(37) = 2.28$, $p = .029$, $d = 0.37$), whereas there was a delay of (at least) one block in the onset of conscious knowledge as indexed by wagering (block 6), M = 0.59; $t(39)$ = 2.23, $p = .031$, $d = 0.35$. This last result replicates what was observed in the simple wagering group of Experiment 2, namely a delay in the onset of awareness. In both groups, deck discrimination became significant at block 5, while advantageous wagering did not become significant until block 6 (Experiment 3, wagering) or block 7 (Experiment 2, simple wagering). In fact the data from the two groups are more similar still, as in the present wagering group wagering was not significantly greater than chance in blocks 7, 8, and 9.

A 3 (group) × 10 (block) mixed ANOVA on the mean proportion of good deck selections showed no main effect of group, *F*(2, 115) = 0.88, *MSE* = 15.05, p =.42, η_G^2= 0.004, but there was a significant effect of block *F*(7.38, 848.97) = 47.86, *MSE* = 3.65, $p <$ .001, η_G^2= 0.22. Also, no significant interaction between group and block (main effect) was observed, *F*(14.76, 848.97) = 0.73, *MSE* = 3.65, p = .75, η_G^2= 0.008 (Greenhouse-Geisser correction). In general, these results suggest that the acquisition of the advantageous strategy was not substantially affected by the different subjective measures of awareness and participants were able to learn to discriminate between the decks based on their overall expected values.

The second important conclusion from this analysis refers to the pattern of overall deck selections; despite the fact that participants learned to discriminate between the decks, this learning effect was rather weak. Figures 3D-F illustrate that participants did not take into account the infrequent but rather large losses in deck B as this deck was selected as often as deck D, showing a strong loss-frequency effect. Interestingly, deck B was the overall deck of choice in the 4-points confidence group (Figure 3E).

The same type of analysis was applied to mean performance on the awareness measures. The analysis revealed a significant main effect of condition, *F*(2, 115) = 3.96, *MSE* = 11.68, *p* = .022, η_G^2=0.02, which was mainly driven by a significant difference between the overall means of binary confidence ratings (*M* = 0.59) and wagering (*M* = 0.52) (Tukey HSD, *p* = .016). No other significant differences between the three measures were observed. The main effect of block was significant, *F*(7.63, 877.57) = 21.41, *MSE* = 3.70, $p < .001$, η_G^2=0.12, indicating that participants' responses in the confidence and wagering measures were consistent with learning of the advantageous strategy. Participants were able to demonstrate conscious knowledge which closely tracked their decisions. Also, the interaction between group and the block main effect did not reach significance, $F(15.26, 877.57) = 1.04$, $MSE = 3.70$, $p = .41$.

Analysis of the 4-point confidence ratings. We examined the 4-point confidence ratings in order to provide a more detailed assessment of conscious knowledge in the IGT by employing a nonparametric receiver operating characteristic (ROC) analysis. Two separate ROC curves were constructed, one before the onset of good deck selections (blocks 1-5) and one after (blocks 6-10). Deck selection performance did not significantly change across blocks 6-10, $F(4, 148) = 0.97$, $p = .43$, allowing for a finer examination of the respective ROC curve. Figure 4 shows that the probability of selecting a good deck gradually increases with confidence in blocks 6-10 whereas the straight ROC line for blocks 1-5 is indicative of a poor relationship between accuracy and confidence. The Type 2 sensitivity derived from these curves (*A*, the area under the ROC curve) indicated above-chance (.50) metacognitive discriminability for blocks 6-10, $A = .65$, 95% CI [.63 .68], but not for blocks 1-5, $A = .48$, 95 CI [.46 .51] (for the calculation of confidence intervals see Delong, Delong, & Clarkepearson, 1988). In addition, fitting the ROC model to each individual participant for blocks 6-10 revealed substantial variability across participants (see Figure 4B).

This fine-grained assessment of the confidence-accuracy relationship suggests that participants' decisions were accompanied by fairly accurate confidence reports. It is also important to investigate how participants utilized the confidence rating scale and whether there was any involvement of unconscious or implicit knowledge after the onset of good deck selection (blocks 6-10). The latter was assessed by using the *guessing criterion* (Dienes et al., 1995) according to which unconscious knowledge is present when participants can discriminate between good and bad decks at above chance levels when they are guessing or their confidence is low. We calculated the percentage of good deck selections for each confidence level. Importantly, at neither of the two low-confidence levels (i.e., 1 = “I’m guessing” and 2 = “I’m not confident”) did deck selection significantly exceed chance (0.50) (Means for each level: 1 = 0.47, 2 = 0.49, 3= 0.72, 4 =0.78), indicating that good deck selections were not made under conditions of low confidence and that conscious knowledge strongly associated with above-chance performance on the IGT. Also, the mean confidence following good deck selections was 2.66 (*SEM* = 0.10) and for bad deck selections was 2.08 (*SEM* = 0.09). The difference between these values was significant, $t(37) = 8.50$, $p<.001$, suggesting the same conclusion as the guessing criterion. Participants were more confident when they made a good than a bad deck choice.

Discussion

The present experiment provides another demonstration of the involvement of conscious knowledge in the IGT. When participants started to consistently sample from the good decks, they were able to report their acquired knowledge through their confidence ratings. However, post-decision wagering showed a similar pattern as in the simple wagering condition of Experiment 2, namely a lag in the onset of wagering compared to deck selection. While this latter pattern might be indicative of unconscious processes in choice behavior, the results from the confidence groups suggest a simpler explanation, namely that wagering is an insensitive measure of awareness.

The confidence rating scales produced similar results when the 4-point scale was collapsed into two categories. A more detailed examination of the continuous scale revealed that participants’ deck selections were accompanied by accurate confidence ratings. Specifically, the ROC analysis showed increased metacognitive monitoring after the point at which performance on the IGT began to exceed chance. While the presence of conscious knowledge does not necessarily mean that unconscious or implicit processing is absent, using the guessing criterion we showed that confidence ratings and deck selections are highly related to one another.

Experiments 4A and 4B

Experiment 2 showed that the exact form of the pay-off matrix can affect participants' wagering strategy, with the Clifford et al. (2008) payoff matrix bringing forward by several blocks the point at which above-chance awareness was located. The sensitivity of wagering to small procedural changes undermines its reliability as a measure of awareness. Yet the results of Experiment 2 might nevertheless encourage the view that wagering under the modified matrix is an accurate measure (and the results of Experiment 1, in which wagering again developed early, might be interpreted in the same way). Even though wagering tracks choice under the modified matrix, does this mean that wagering is a reliable and sensitive measure of awareness? In Experiment 4A we address this question by measuring awareness both with Clifford et al.'s payoff matrix and simultaneously with Maia and McClelland's (2004) quantitative questions in a probabilistic alternative version of the IGT. Experiment 4B is a replication of Experiment's 2 modified wagering condition with the inclusion of Maia and McClelland's questionnaire.

Experiment 4A

Method

Participants. Twenty-one volunteers participated (13 females, age *M*=23.45, *SD*=3.56), all of whom were recruited via the departmental subject pool. They were paid £2 for their participation and an additional amount between £0 and £3, depending on their performance in the task.

Task. A variation of the original IGT was employed in which the allocation of wins and losses on each trial was sampled at random from the overall distribution (for a similar task see Schonberg, Daw, Joel, & O'Doherty, 2007). This modification removes many of the complications that arise from using the typical IGT structure in which the disadvantageous decks are initially good (because losses do not occur early in the task), eliminating the predominant preference for the bad decks (see Fellows & Farah, 2005). The payoff structure of each deck was different from the original IGT; the pay-off matrix of Clifford et al. (2008) was used to determine the payoffs received by participants on each trial, in such a way that the amount won or lost was dependent on card selection and wagering. For example, based on the contingencies of Table 1, a payoff of 2 is always associated with a good deck selection and a low wager. Whether this amount was a win or loss was defined by the distribution of outcomes associated with each deck. Specifically, for decks A and B, the probability of a loss was .75 and .60 respectively, whereas for decks C and D, the probability of a win was .75 and .60, respectively, resulting in different overall expected payoffs for each deck. In contrast to the original IGT (where the win on each trial could be coupled with a loss), the outcome on each trial was either a net win or a loss and participants could win or lose points, not real or facsimile money.

The task comprised 100 card selections. Each deck had 60 randomly predefined wins and losses based on the probabilities programmed for that deck. After each card selection, participants could place a wager, either High or Low, on their card selection. Based on the combination of deck selection and wagering, participants were presented with a single amount, either a win or a loss. Along with wagering, participants' conscious knowledge was assessed using a modified version of Maia and McClelland's (2004) questionnaire. The qualitative parts of the questionnaire were omitted and it was administered every 20 trials.

Procedure. The procedure of Experiment 4A was identical to that of previous experiments.

Results and Discussion

Choice and Wagering. The method for identifying the onset of good deck selections and advantageous wagering was the same as in previous experiments. Performance exceeded the chance level on block 1 for both measures (Choice: *M* = 0.59, *t*(20) = 2.83, *p* = .01, *d* = 0.62, Wagering: *M* = 0.65, *t*(20) = 3.80, *p* = .001, *d* = 0.83) (see Figure 5A).

A repeated-measures ANOVA revealed a significant effect of block on good deck selections, *F*(9, 180) = 12.40, *MSE*= 2.32, *p* <.001, η_G^2 = 0.28. Wagering performance closely followed the optimal decision-making strategy as demonstrated by a main effect of block, *F*(4.92, 98.46) = 4.92, *MSE* = 2.23, *p* <.001, η_G^2=0.13. These findings are consistent with the previous results relating to the modified payoff matrix, indicating no dissociation between performance and awareness. In fact, the pattern of both good deck selections and advantageous wagering is similar to the modified wagering condition in Experiment 2, albeit with accelerated learning.

Rapid learning can be explained by the probabilistic allocation of wins and losses on each trial. Fellows and Farah (2005) found that in their shuffled IGT version (the order of the decks was changed so that losses from the bad decks occurred at the start of the task) normal control participants selected more cards from the good decks even in the first 20 trials and they kept on choosing the good decks throughout the task. Our probabilistic version of the payoff schedule removes the reversal learning component (that is, to learn that the decks which yield higher rewards are disadvantageous in the long run) of the IGT which can be slow and delay learning of the optimal decisions.

Since each deck had different overall expected payoffs we investigated whether participants could discriminate not only between good and bad decks but also within each pair of decks (A vs B and C vs D). Participants selected more cards from the good decks in all blocks, *t*(20) = 12.02, *p*<.001, and this tendency increased from block 1 to block 5. Also, they selected more cards from deck C compared to deck D, $t(20) = 3.97$, $p<.001$, $d = 0.87$. No significant difference was observed between selections from decks A and B across blocks, although participants tended to select more cards from deck B.

Questionnaire. Participants' knowledge regarding the advantageous strategy was further supported by the different measures of the questionnaire. Figure 5A shows that they exhibited substantial knowledge about the quality of each deck, even in the first assessment of awareness (trial 20). In fact, the observed pattern is similar to that in Experiment 1. Importantly, the mean ratings for each deck give further support to the pattern of deck selections shown in Figure 5B. Not only are the good decks selected more often than the bad decks, but also participants' ratings agree with the expected value of each deck. Table 4 shows that deck C is evaluated more positively than deck D even though both decks are advantageous. In other words, knowledge about the quality of each deck led participants to select more cards from deck C. Similarly, deck A (which has a higher probability of loss compared to deck B) has the lowest mean rating.

However, the two measures of awareness are not directly comparable based on the information shown in Figure 5A. We applied the same procedure as in Experiment 1 to test whether the proportion of participants who preferred a good deck in the deck-selected measure (.81) is significantly different from the proportion classified as aware of the optimal strategy based on wagering (.76) on trials 16-25. The McNemar test for dependent proportions was not significant, $\chi^2(1)= 0.2$, $p = .65$.

Another way of examining the two measures is to look at participants' deck selection and wagering in the trials following the administration of the questionnaire (trials 21, 41, 61, 81; we also include trial 100 immediately prior to the final administration of the questionnaire). Specifically, we are interested in the verbal reports and wagers of those participants who behave advantageously (i.e., select good decks) in these trials. Figure 6 shows that the majority of participants demonstrate knowledge of the advantageous strategy in all the questionnaire items. However, wagering underestimates the acquired knowledge in all trials following the questionnaire compared to the verbal reports. Thus, it is evident that the detailed and structured questions reflected high levels of awareness compared to wagering.

Experiment 4B

Method

Participants. Nineteen volunteers participated (10 females, age *M*=24.95, *SD*=3.15) from UCL's subject pool. As in Experiment 4A, they received £2 for participation and an additional fee up to £3 dependent on their performance in the task.

Task. The decision-making paradigm was identical to the modified wagering condition of Experiment 2, that is, the payoff schedule was the same as in the original IGT and wagering was expressed as a binary choice ("High" and "Low"). The extra component of this experiment was the questionnaire of Maia and McClelland (2004) which was administered every 20 trials.

Procedure. The procedure was identical to that of previous experiments.

Results and Discussion

Choice and Wagering. The mean probability of selecting a good deck and making an advantageous wager exceeded chance on block 5 for both measures (Choice: M = 0.67, $t(18)$ = 3.21, p = .005, d = 0.70, Wagering: M = 0.65, $t(18)$ = 3.51, p = .003, d = 0.77) (see Figure 7A). Compared to the onset of learning and awareness in Experiment 2, there seems to be a lag of one block. Despite the fact that both measures are numerically above chance on block 4 (*M* Choice=0.57, *M* Wagering=0.53), neither is significant.

A repeated-measures ANOVA showed significant main effects of block on choice, $F(9, 162)$ = 12.72, p <.001, η_G^2=0.32, and wagering, $F(9, 162)$ = 8.81, p <.001, η_G^2=0.28.

These results agree with our previous experiments where we used the Clifford et al. (2008) matrix (Experiment 2, modified wagering group; Experiment 4A). Learning of the good decks and awareness progress in the same manner and no dissociation is observed.

Questionnaire. The proportion of participants whose responses favored the good decks is illustrated in Figure 7A. The majority of participants showed a preference for the good decks in the verbal questions except at the first question period where the proportion was lower but still above chance.

The mean ratings for each deck (see Table 4) converge with the profile of deck selections. Deck D has the highest mean rating which explains why this deck is selected more often than the other decks see (Figure 7B). Even though decks C and D share the same overall expected values, the small probability of loss on deck D affects the perceived goodness of this deck. The same principle applies to deck B too; despite its overall negative appraisal, it is selected as often as deck C. Also, the high probability of loss on deck A in conjunction with the negative expected value led participants to negatively evaluate and to avoid selecting cards from this deck.

In order to compare how sensitive the two methods are in assessing conscious knowledge we again examined the proportion of participants who behaved advantageously in the trials following the administration of the questionnaire (we again include trial 100 which immediately preceded the final set of questions). Figure 8 demonstrates that in all question periods the proportion of participants who translated their knowledge into a high wager is less than the proportion who favored the good decks in their verbal reports. This pattern suggests that wagering underestimated participants' acquired knowledge and the more elaborated questions detected higher levels of awareness. Despite the fact that wagering closely tracks deck selections, it is not therefore an exhaustive and sensitive method to measure awareness. This conclusion is supported by a significant difference between the proportion of participants who opted for one of the good decks in the deck-selected measure (.63) and the proportion classified as aware based on wagering (.32) in the first administration of the questionnaire, $\chi^2(1) = 6$, $p = .014$.

Discussion of Experiments 4A and 4B

The key point of Experiments 4A and 4B is that even though wagering closely tracks deck selection and learning, it underestimates what participants have learned about the task and deck contingencies. This also applies to the results of Experiment 2 where we found that small procedural changes can affect the extent to which wagering tracks deck selection.

Finally, the analysis based on the trials following the administration of the questionnaire suggests that acquired knowledge is not automatically translated into an appropriate wager after a deck selection (Figures 6 and 8). Why is this? A possible reason is loss aversion. The prospect of losing more money/points even if knowledge is above guessing levels can be aversive.

General Discussion

The task of validating measures and methods of assessing awareness is an important endeavour within psychological science as from the very beginnings of experimental psychology, researchers have been interested in the distinction between conscious and unconscious mental states (Dienes, 2008). In the present article we put post-decision wagering under careful scrutiny because it is a method that supposedly removes biases and complications associated with verbal judgments of conscious knowledge and it has been extensively used in many areas of experimental psychology. Our purpose was twofold: first, to evaluate post-decision wagering as a sensitive and direct method of awareness, and secondly to investigate whether the claims of Persaud et al. (2007) about implicit influences on decision-making under uncertainty are valid. A careful examination of wagering in comparison with other measures of awareness such as confidence ratings and quantitative questions also allowed us to explore the type of information that is essential for optimal decision-making and how participants use their acquired knowledge to make decisions in uncertain environments.

The results of the present experiments do not offer any support for the claims of Persaud et al. (2007) that learning to make advantageous decisions can occur in the absence of awareness. As noted in the Introduction, research evaluating awareness in the Iowa Gambling Task has formed a prominent and major element of the wider claim that unconscious thoughts and signals can influence choice (Nisbett & Wilson, 1977). The present work therefore bolsters recent suggestions (e.g., Newell & Shanks, 2014) that it is premature to assign a fundamental role to such processes in theories of decision-making.

Experiment 1 was a near exact replication of Persaud et al.'s study. However, we only replicated the results relating to the quantitative questioning group where deck selection and advantageous wagering exceeded chance at the same time. In contrast to Persaud et al.'s results, the same pattern was observed in the group that was asked only to make a wager after their deck selection, suggesting no dissociation between choice and wagering.

In Experiment 2, following the criticisms about the dominance of high wagers in Persaud et al.'s (2007) pay-off matrix, we tested the matrix proposed by Clifford et al. (2008) using the reward and punishment schedule of the original IGT. Despite the fact that there was a difference in the onset of learning and awareness in the simple wagering condition, no such difference was observed in the modified wagering group. Thus we were able conceptually to replicate Persaud et al.'s finding of a lag between choice and wagering, but a simple change in the weights of the pay-off matrix was sufficient to make wagering a more sensitive method.

In Experiment 3, we compared wagering with confidence ratings in an attempt to identify structural differences between the two measures and to provide a better examination of knowledge assessment in the IGT by employing a 4-point confidence scale. While both confidence scales (binary and continuous) showed conscious knowledge of the advantageous strategy in the IGT, this was not the case for wagering, where we again replicated Persaud et al.'s finding of a lag between choice and wagering. Thus wagering is a less sensitive measure of awareness than confidence ratings. Also, knowledge in the IGT seems to be completely conscious: when we applied the guessing criterion (Dienes et al., 1995) to our data, there was no evidence of unconscious processing.

The purpose of Experiment 4 was to measure wagering concurrently with explicit questioning. Experiments 1 and 2 (modified wagering condition) showed that wagering can closely track learning, but is that alone an adequate indicator of a robust method of measuring awareness? We employed the questionnaire of Maia and McClelland (2004) in order to examine how well wagering performs in comparison to another method of awareness. The results showed that even though wagering followed deck selections, it is not a sensitive index of awareness as it underestimates the knowledge that participants possess. We compared the proportions of participants classified as consciously aware by the two measures. No significant differences were observed in two of the experiments because of the small sample sizes, even though more participants were identified as aware according to the questionnaire. We ran the same analysis on the pooled data across experiments (N=55) and indeed there was a significant difference between the deck-selected measure (.71) and wagering (.49), $\chi^2(1) = 7.2$, $p = .007$, indicating that there is some conscious knowledge about the task that is left undetected by wagering (see Figure 9).

One possible criticism of the quantitative questions employed here and by Maia and McClelland (2004) is that they might have a reflexive effect on the very property they are attempting to measure, namely awareness. Recall that Persaud et al. found that the onset of advantageous wagering was brought forward by as much as 30 trials when participants also had to periodically answer quantitative questions. We saw no hint of such a pattern in Experiment 1.

It is important to emphasize that although our conclusions are very different from those of Persaud et al. (2007), this is not because of any substantial disagreement about the fundamental data patterns (apart from the aspect just mentioned). On the contrary, we were able to reproduce the key finding they reported – a lag between deck discrimination and the onset of advantageous wagering – in the simple wagering group of Experiment 2 and the wagering group of Experiment 3. It is true that the conditions in which we obtained this pattern were slightly different from those in which Persaud et al. obtained it (for example, in our studies it depended on using the original IGT payoff schedule – see Table 2) and that in the no questioning group of Experiment 1 we did not obtain it, despite the fact that this group comprised a near-exact replication of Persaud et al.'s experiment, suggesting that some subtle procedural factors influence whether or not a lag occurs. Where we are in disagreement is in the interpretation of this lag. Whereas Persaud et al. took it as evidence of unconscious influences in decision making that drive deck selections before participants become aware and able to wager adaptively, we take the lag as evidence of the insensitivity of wagering. Our case for this conclusion rests on the finding that the lag was eliminated or indeed reversed as a result of (1) a minor change in the payoff matrix in the modified wagering group of Experiment 2, (2) a switch from a binary wager response to either a binary or a 4-point confidence response in Experiment 3, and (3) employing explicit verbal questions such as "if you could only select cards from one of the decks until the end of the game… which of the four decks would you pick?" to assess awareness.

Evidence against implicit influences

The claim that unconscious or implicit biases are essential for successful performance in the IGT has not been confirmed in any of the experiments reported here. In fact, participants' explicit conscious knowledge runs in parallel with their deck selections. Specifically, when participants' awareness is measured by the detailed questionnaire, a positive correlation between ratings and deck selections is observed (see Tables 3 and 4). Dunn et al. (2006) suggested that there is little evidence to support the view that deck contingencies are consciously impenetrable and what needs to be tested is whether participants have an explicit understanding of the reward and punishment schedule or whether they can merely discriminate the quality of the decks by attributing positive or negative valences to each one. In fact, our questionnaire results demonstrate that participants not only were able to show a general preference for the good decks but could also accurately justify their preferences. For example, in Experiment 4A where each deck had different expected values, participants made more choices from the deck with the highest expected value (deck C) and they gave more positive ratings to this deck compared to the other good deck (deck D, with a lower expected value).

The important role of conscious knowledge in the IGT is supported by a study (Gutbrod et al., 2006) with amnesic patients whose deck selections were no better than chance indicating that explicit task knowledge is essential for shaping a behavioral preference towards the advantageous decks. Gutbrod et al. argued that the causal link between SCRs and behavior "might not be straightforward and that a lack of explicit task knowledge may be sufficient to explain why most of our patients failed to acquire a behavioral preference in the IGT" (p. 1323). Similar findings were also reported by Gupta et al. (2009) who suggested that declarative memory plays a significant role in forming and updating the representation of rewards and punishments associated with each deck. In addition, Stout, Rodawalt, and Siemers (2001) found that IGT impairments in Huntington's disease patients were significantly correlated with explicit memory deficits.

In a recent study, Fernie and Tunney (2013) presented evidence suggesting that autonomic activity or somatic markers are not important determinants of successful performance on the IGT. They observed that conscious knowledge developed after approximately 40 trials and was correlated with advantageous deck selections. Their main results showed that aSCRs did not discriminate between decks prior to the emergence of explicit knowledge, while reward SCRs differentiated between good and bad decks only for those participants who had already acquired some knowledge about the decks' quality. Another interesting finding relates to the punishment SCRs; these were found to be of greater magnitude following larger losses from the bad decks in the initial stages of the task but not after the emergence of knowledge, indicating that participants became aware that the bad decks produce big losses.

The previous findings highlight the importance of cognitive processes underlying performance on the IGT and offer support for the view that emotional or affective signals may not be as important as previously believed. Even though the involvement of emotion-driven learning of the task structure and deck contingencies cannot be entirely ruled out (see Wagar & Dixon, 2006), many studies have pointed out that the contribution of emotional information is rather limited. For instance, the decision-making impairments of VMPFC patients on the IGT can be explained by cognitive deficits (e.g., reversal learning) rather than by any inability to generate emotional or somatic markers (Maia & McClelland, 2005). When the reversal learning component is removed, VMPFC patients' performance on the IGT is comparable to that of normal controls (Fellows & Farah, 2005). The results of our experiments are in agreement with a range of studies in the decision-making literature regarding the importance of conscious knowledge (for a comprehensive review see Newell & Shanks, 2014). When appropriate and sensitive measures of awareness are employed, evidence of unconscious processes is surprisingly weak.

Computational models of the IGT assume different kinds of factors such as cognitive, motivational, and response processes (e.g., Busemeyer & Stout, 2002). Hence, future research could try to decompose these processes/mechanisms and ascertain their contribution when participants make decisions. It is possible that wagering is more sensitive to the emotional/ motivational components of decision-making and thus a poor indicator of the acquisition of conscious knowledge. Moreover, Pasquali, Timmermans, and Cleeremans (2010) argued that advantageous wagering can be acquired in the absence of awareness which would make it an unsuitable measure of awareness in the IGT (see also Dienes & Seth, 2010). This could explain the results shown in Figure 9, namely that explicit questioning (i.e., which of the four cards would you pick until the end of the task?) can elicit higher levels of awareness than wagering.

Decision-making in the IGT

The IGT has been widely employed as a standard tool for studying decision-making in clinical populations and also as a task to measure decision-making under uncertainty in healthy participants. However, there is no consensus in the vast IGT literature regarding the features of the decks that are most important in shaping decision-making strategies. Initially, Bechara et al. (1994) suggested that normal participants begin to consistently select good decks after an exploration phase. The driving force for this selection pattern is the overall expected values associated with each deck. Decks with a positive total outcome are selected more often compared to ones with a negative outcome, regardless of other confounding factors such as the probability and magnitude of losses. The crucial assumption is that normal participants will always learn the advantageous strategy in a canonical and predictive manner.

However, many of the early assumptions about the IGT have been questioned in light of recent experimental evidence. Steingroever et al. (2013) conducted a literature review on IGT studies and concluded that the major assumptions relating to decision-making in healthy participants are essentially invalid. Specifically, there is often no clear preference for good over bad decks, choice behavior across decks is not uniform, and the usual exploration-exploitation trade-off is rarely observed. Instead people seem to prefer the decks with infrequent losses (decks B and D) with no explicit tendency to exploit the most rewarding options. Similarly, Horstmann, Villringer, and Neumann (2012) concluded that the factors that influence performance in the IGT (in descending order of importance) are: gain frequency, loss frequency, and overall expected value. The results from the present experiments are broadly in line with these findings. In the experiments that used the standard IGT payoff schedule, participants' choices were predominantly guided by loss frequency, and deck D was selected more often than any other deck. The interesting finding is that deck B, which is a disadvantageous deck, was selected as often as deck C, even though the latter has a positive expected value, and in some cases was selected as often as deck D (see Experiment 3). In fact, a clear preference for the good decks was only observed in Experiment 1, where participants selected decks C and D more often than decks A and B.

Our results also show that participants can be sensitive to differences among the decks regarding their overall expected value. In Experiment 4A, the most profitable deck (deck C) was favored and there was no overall difference between the decks with a negative total outcome. The key finding of this experiment was that participants were able to grasp the payoff structure very early in the task, which suggests that difficulties participants experience in the classic IGT may be associated with its idiosyncrasies. First, when participants encounter the initial loss in deck B on trial 9, they may think of it as a rare event and keep selecting cards from this deck. Secondly, the concurrent presentation of wins and losses might make it harder to acquire the optimal strategy. Thirdly, it has been shown that 100 trials are not sufficient for participants to learn and exploit the advantageous decks (Fernie & Tunney, 2008; Wetzels, Vandekerckhove, Tuerlinckx, & Wagenmakers, 2010).

We have suggested that loss aversion may be an important concept for understanding wagering behavior in the experiments reported here. For example, one reason why wagering may underestimate awareness compared to verbal reports (Figure 9) is that participants may simply be averse to the large losses that can follow high wagers. Although it means foregoing large gains, wagering low minimizes the likelihood of large losses, even when one has some confidence about which are the good decks. We did not directly measure participants' degree of loss aversion and acknowledge that employing it as an explanatory concept is speculative. Further research in which loss aversion and IGT wagering are separately measured will be valuable.

Variation between and within studies. Yet another problematic aspect of the IGT is that participants do not exploit the most profitable decks but instead go back to select cards from the disadvantageous decks, especially deck B. Specifically, most IGT studies report only a weak overall preference for the good decks, between 50% and 60% (Steingroever et al., 2013), with continued sampling from deck B. The results from our experiments, where we employed a payoff structure similar or identical to the original IGT, are in reasonable accordance with these percentages (Experiment 1 = 66%, Experiment 2 = 62.2%, Experiment 3 = 55%, Experiment 4B = 60%; weighted mean across experiments 58.7%). However, in the experiments reported here, we assessed awareness concurrently (wagering, confidence ratings, and questionnaire) with decision-making and this may have had an effect on deck-selections, making participants more attentive to the deck payoffs. For instance, participants may focus more on the task knowing that they will have to answer specific questions about the decks. Similarly, Cella, Dymond, Cooper, and Turnbull (2012) argued that the systematic assessment of participants' awareness may facilitate performance on the IGT.

The same also applies to wagering as the tendency to maximize winnings can increase participants' motivation to perform well in the task (Sandberg et al., 2010). In fact, Szczepanowski et al. (2013) found that performance on a cognitive task (detection of fearful faces) was increased when post-decision wagering was simultaneously used as a probe of conscious knowledge, suggesting that financial incentives can motivate participants to perform better on the primary task. Another aspect of using post-decision wagering is the magnitude change in payoffs, as wagers in our tasks were employed as multipliers of the actual deck payoffs. Better ability to discriminate between good and bad decks has also been observed in other IGT studies in which participants' awareness was assessed at the same time as their decision-making performance (see Dymond, Bailey, Willner, & Parry, 2010; Evans et al., 2005; Maia & McClelland, 2004; Persaud et al., 2007; Wagar & Dixon, 2006).

Concluding remarks and limitations

In the experiments reported here, we obtained results at odds with the predictions of the somatic marker hypothesis regarding the activation of an unconscious emotional system, which is assumed to provide information about the outcome of the decision-making process. Decision strategies in the IGT rely almost exclusively on acquired conscious knowledge about the properties of the decks. The second major point of the present article is that caution is advised when drawing conclusions about the existence of implicit influences in decision-making under uncertainty when unsuitable methods of measuring awareness are used. Persaud et al.'s (2007) conclusions seem ungrounded because of the pronounced failure of post-decision wagering to measure awareness with adequate sensitivity. We have shown that wagering underestimates awareness by comparison to other methods, and that wagering strategies are affected by the design of the pay-off matrix.

The overall utility of post-decision wagering as a reliable measure of awareness needs to be further examined under different settings (e.g., different pay-off matrices, no-loss gambling in order to remove the effect of loss aversion) and other experimental conditions, as it seems to be unsuitable in a context (the IGT) where the first-order task also involves gambling. The results and conclusions of the current article only extend to the IGT and further evaluations of post-decision wagering are needed using different behavioral tasks or populations. For instance, Persaud et al. (2007) reported a dissociation between awareness (as measured by wagering) and behavior in three different tasks: artificial grammar learning, blindsight, and the IGT. However, our findings are consistent with other studies which have shown that wagering is no more reliable or exhaustive than confidence ratings (e.g., Dienes & Seth, 2010; Szczepanowski et al., 2013; Wierzchon et al., 2012). In a recent re-analysis of Szczepanowski et al.'s (2013) study which compared three subjective measures of awareness (post-decision wagering, confidence ratings, and perceptual awareness scale [PAS] ratings), Sandberg, Bibby, and Overgaard (2013) found that confidence and PAS ratings were significantly more sensitive than post-decision wagering. If we are to measure awareness as accurately and sensitively as possible, the results from different methods should be combined in order to provide a finer and deeper examination of claims involving implicit or unconscious influences.

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Footnote

[1] We ran a further group of participants (*N*=20) under conditions identical to the control group of Experiment 1 in order to check whether the pattern of results was reproducible. There was again no evidence for a dissociation between deck selection and wagering: both measures became reliably better than chance on block 6, somewhat later than in the control group of Experiment 1 (block 4). The percentage of good deck selections across blocks was 59.3% (A=.13, B=.28, C=.28, D=.31), indicating a weaker learning effect compared to the control group of Experiment 1 (63.8%).

Table 1

Pay-off matrices for the different combinations of deck selection and wager

	Persaud et al.		Clifford et al.	
	Deck Selection			
Wager	Good	Bad	Good	Bad
Low	+1	-1	+2	-1
High	+2	-2	+5	-5

Table 2

Outline of the Experiments

		Experiment						
	Persaud et al. study	1		2		3	4A	4B
		QQ	NQ	SW	MW			
Payoff matrix	P	P	P	P	C	P	C	C
Reward/Punishment Schedule	P	P	P	IGT	IGT	IGT	Prob	IGT
Wagers	10/20	10/20	10/20	1/2	H/L	1/2	H/L	H/L
Reward/Punishment	Separated	Separated	Separated	Separated	Separated	Separated	Combined	Separated
Performance-related remuneration	✗	✗	✗	✗	✗	✓	✓	✓
Other Measures	qst	qst	✗	✗	✗	CR	qst	qst

Note. QQ = Quantitative questioning, NQ = No questioning, SW = Simple wagering, MW = Modified wagering, P = Persaud et al. (2007), C = Clifford et al. (2008), IGT = original Iowa Gambling Task, Prob = probabilistic, H = High, L = Low, qst = Maia and McClelland's questionnaire, CR = Confidence ratings.

Table 3

Mean ratings and proportion of selections for each deck in Experiment 1

Deck	Mean Ratings (*SD*)	Proportion of Selections: Questionnaire Group	Proportion of Selections: Control Group
A	-3.01 (3.69)	0.12	0.12
B	-2.71 (4.86)	0.20	0.24
C	0.67 (3.37)	0.33	0.30
D	2.17 (3.33)	0.34	0.34

Note. The mean ratings come from the questionnaire group.

Table 4

Mean ratings and proportion of selections for each deck in Experiment 4

	Experiment 4A		Experiment 4B	
Deck	Mean Rating (*SD*)	Proportion of Selections	Mean Rating (*SD*)	Proportion of Selections
A	-5.32 (3.61)	0.09	-2.46 (4.39)	0.15
B	-2.94 (4.40)	0.11	-1.47 (5.51)	0.25
C	5.60 (2.98)	0.42	1.58 (3.39)	0.25
D	4.31 (3.29)	0.38	3.52 (4.06)	0.35

Appendix A

Reward and Punishment Schedule of the IGT (Experiment 1)

Trial / Deck	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
A(+2)			-3		-6		-4		-5	-7		-7		-5	-4		-6	-3				-6		-7	
B(+2)									-25					-25							-25				
C(+1)			-1		-1		-1		-1	-1		-0.5	-1.5				-0.5	-1.5		-1				-1	-0.5
D(+1)										-5										-5					
Trial / Deck	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
A(+2)	-4	-5	-3			-7	-4	-5				-3	-6				-5			-7	-6		-3		-4
B(+2)							-25								-25										
C(+1)	-1			1.5	-1				-0.5	-0.5		-1.5		-1	-1.5		-1		-1	-1		-1	-1		
D(+1)				-5						-5											-5				

Note. The payoff schedule was constructed based on the ratio of loss to win of the original IGT. For example, in the original task deck A has a 50% probability of loss. The wins are always £100 and the losses range from £150 to £350. On trial 3 there is a loss of £150. The ratio of loss to win is 1.5. Since the coefficient of win is always 2 in Persaud et al.’s (2007) variation, we multiplied each ratio by 2. This gives us the schedule of the losses. The average wager is (20 + 10) / 2 = 15. For example, for the first 10 trials on deck A the losses are (3 + 6 + 4 + 5 + 7) × 15 = 375 and the wins are (2 × 10) × 15 = 300. The difference is five times the average wager per ten cards [5 × 15 = 75]. We applied this procedure on the remaining decks. The payoff schedule is repeated twice for the 100 trials of the task.

Appendix B

Questionnaire

1. Please rate, on a scale from -10 to +10, how good or bad you think deck A is, where -10 means that it is very bad and +10 means that it is very good.
2. Okay, now suppose that you were to select 10 cards from deck A.
    - 2.1. What would you expect your average result to be?
    - 2.2. For those trials in which you would get a win, what would you expect your average winning amount to be?
    - 2.3. In how many of the 10 trials would you expect to get a loss?
    - 2.4. For those trials in which you would get a loss, what would you expect the average loss to be?
3. Now suppose I told you that you could only select cards from one of the decks until the end of the game, but that you were allowed to choose now the deck from which you would draw your cards. Which of the four decks would you pick?

Figure Captions

Figure 1. Proportion of good deck selections and advantageous wagering across blocks of trials for the control (A) and questionnaire groups (B) in Experiment 1 (lines). The grey diamond and the triangle markers represent the proportion of participants who gave higher rating to one of the two best decks and the proportion of participants who selected one of the two best decks as their choice if they were allowed to select only one deck. The star and the square markers represent the proportion of participants who gave the highest reported expected net and the calculated net to one of the two best decks. Points are offset horizontally so that error bars (± 1 SEM) are visible.

Figure 2. Proportion of good deck selections and advantageous wagering across blocks of trials in the simple wagering (A) and modified wagering groups (B) in Experiment 2. Points are offset horizontally so that error bars (± 1 SEM) are visible. (C, D) Overall proportion of deck selections.

Figure 3. Proportion of good deck selections and advantageous wagering across blocks of trials for each group in Experiment 3 (A-C). Points are offset horizontally so that error bars (± 1 SEM) are visible. (D-F) Overall proportion of deck selections in each group.

Figure 4. (A) Type 2 ROC curves for the blocks before (1-5) and after (6-10) the onset of good deck selections. (B) Distribution of the area under the curve (*A*) when fitting the ROC model to each participant (blocks 6-10).

Figure 5. (A) Proportion of good deck selections and advantageous wagering across blocks of trials in Experiment 4A (lines). The grey diamond and the triangle markers represent the

proportion of participants who gave higher ratings to one of the two best decks and the proportion of participants who selected one of the two best decks as their choice if they were allowed to select only one deck. The star and the square markers represent the reported expected net and the calculated net, respectively. (B) Overall proportions of deck selections. The win probability associated with each deck is depicted on the top of each bar.

Figure 6. Percentage of participants who showed knowledge of the advantageous strategy in the questionnaire items versus in their wagers in Experiment 4A. Wagering indicates the percentage of participants who made an advantageous wager (high on a good deck choice) on the trial immediately following the administration of the questionnaire.

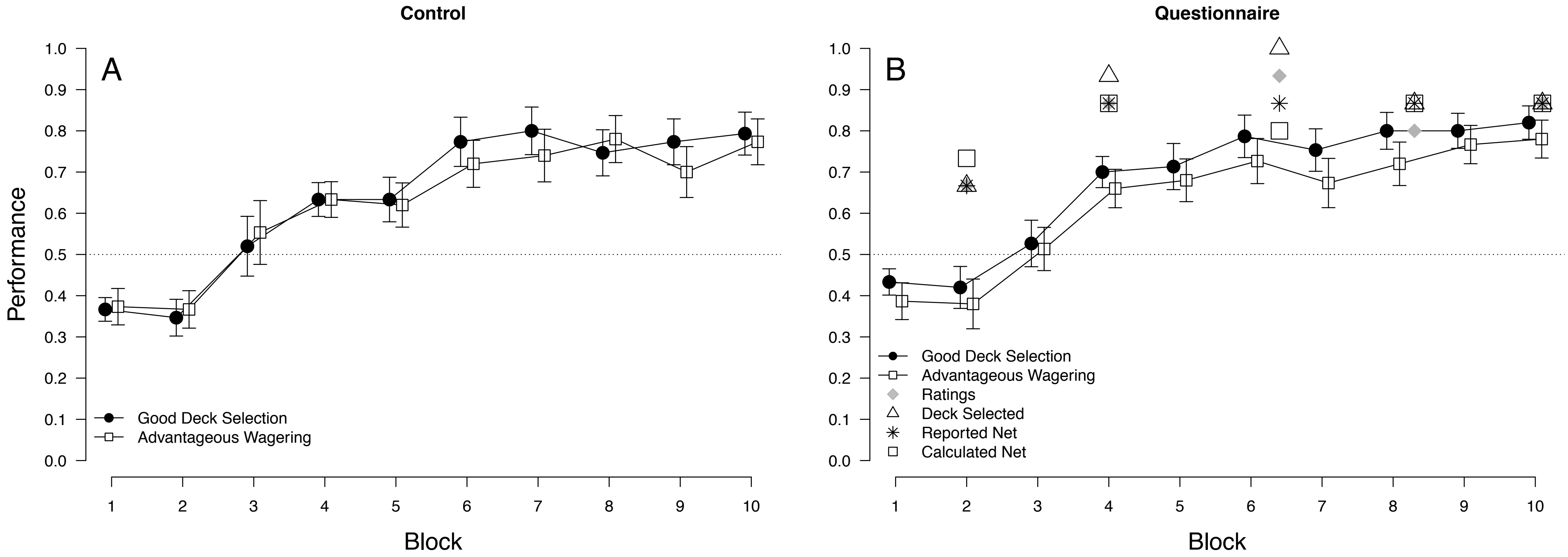
Figure 7. (A) Proportion of good deck selections and advantageous wagering across blocks of trials in Experiment 4B (lines). The grey diamond and the triangle markers represent the proportion of participants who gave higher rating to one of the two best decks and the proportion of participants who selected one of the two best decks as their choice if they were allowed to select only one deck. The star and the square markers represent the reported expected net and the calculated net, respectively. (B) Overall proportions of deck selections.

Figure 8. Percentage of participants who showed knowledge of the advantageous strategy in the questionnaire items versus in their wagers in Experiment 4B. Wagering indicates the percentage of participants who made an advantageous wager (high on a good deck choice) on the trial immediately following the administration of the questionnaire.

Figure 9. Proportion of participants classified as aware and unaware of the advantageous strategy on trial 20 by wagering and the deck-selected question across experiments. Wagering

represents the proportion of participants whose average advantageous wagering on trials 16-25 was equal to or greater than 0.50.

Figure 1



Control
A
Questionnaire
B
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Performance
1
2
3
4
5
6
7
8
9
10
Block
Good Deck Selection
Advantageous Wagering
Ratings
Deck Selected
Reported Net
Calculated Net

Figure 2

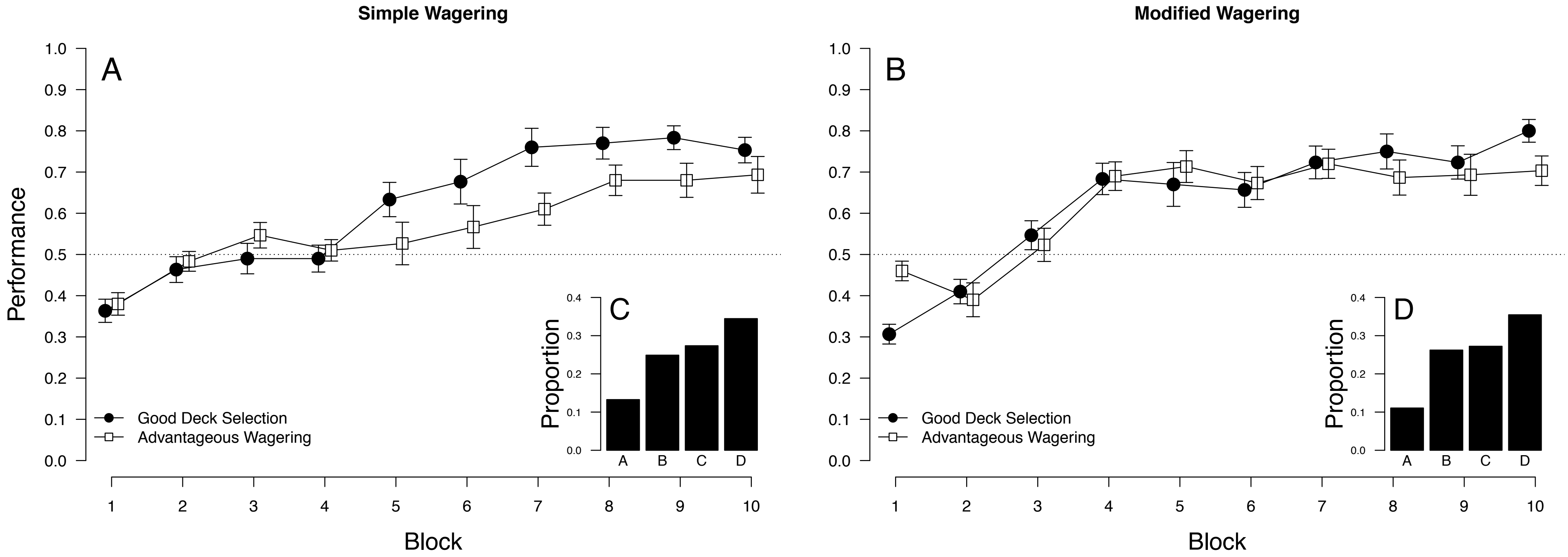
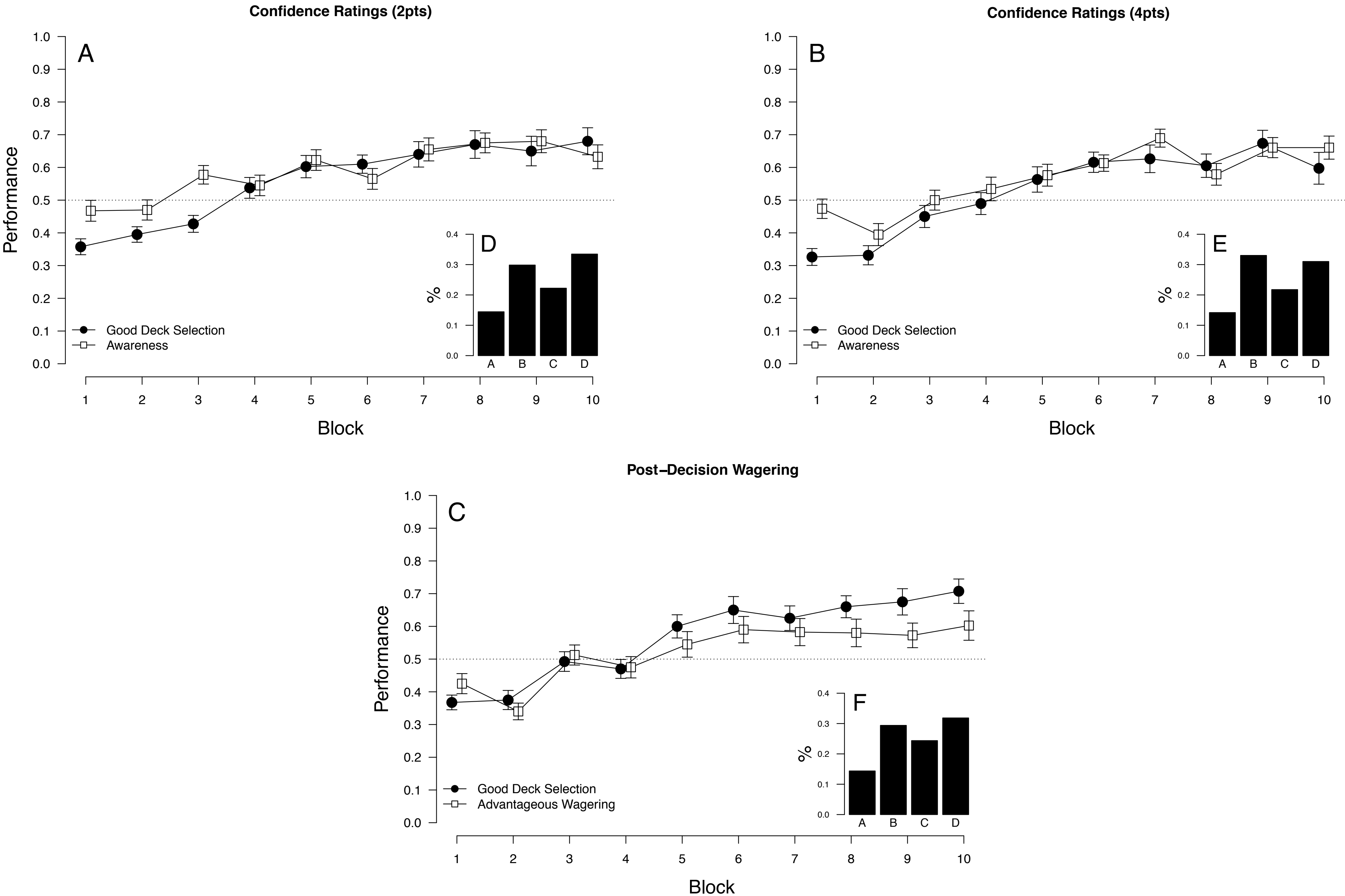
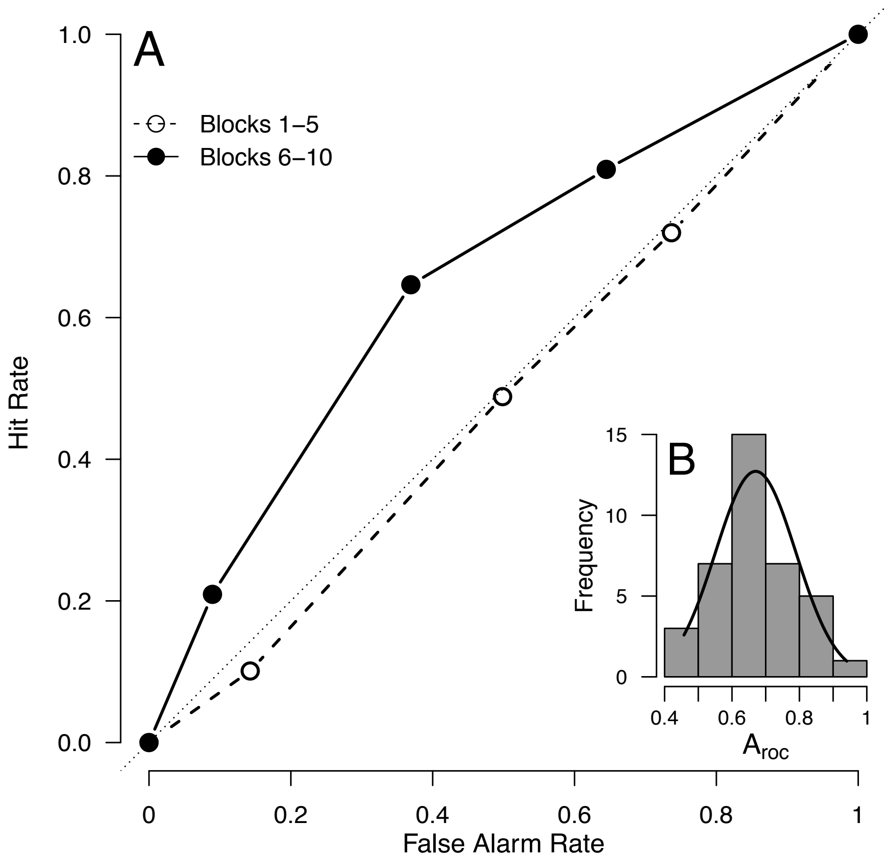

Simple Wagering
Modified Wagering
A
B
C
D
Performance
Proportion
Block
Good Deck Selection
Advantageous Wagering
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
2
3
4
5
6
7
8
9
10
A
B
C
D

Figure 3



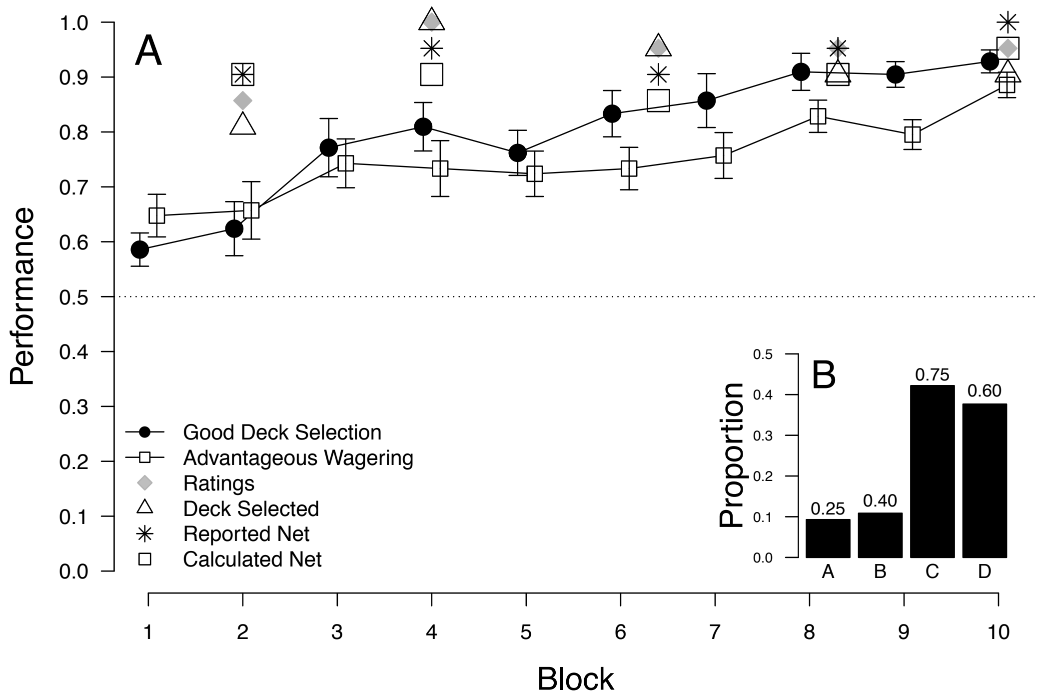
Confidence Ratings (2pts)
A
Performance
Block
Good Deck Selection
Awareness
D
%
A
B
C
D
Confidence Ratings (4pts)
B
Good Deck Selection
Awareness
E
Post−Decision Wagering
C
Good Deck Selection
Advantageous Wagering
F

Figure 4



A
Blocks 1–5
Blocks 6–10
1.0
0.8
0.6
0.4
0.2
0.0
Hit Rate
0
0.2
0.4
0.6
0.8
1
False Alarm Rate
B
15
10
5
0
Frequency
0.4
0.6
0.8
1
A_{roc}

Figure 5



A
B
Performance
Block
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
2
3
4
5
6
7
8
9
10
Good Deck Selection
Advantageous Wagering
Ratings
Deck Selected
Reported Net
Calculated Net
Proportion
0.5
0.4
0.3
0.2
0.1
0.0
0.25
0.40
0.75
0.60
A
B
C
D

Figure 6

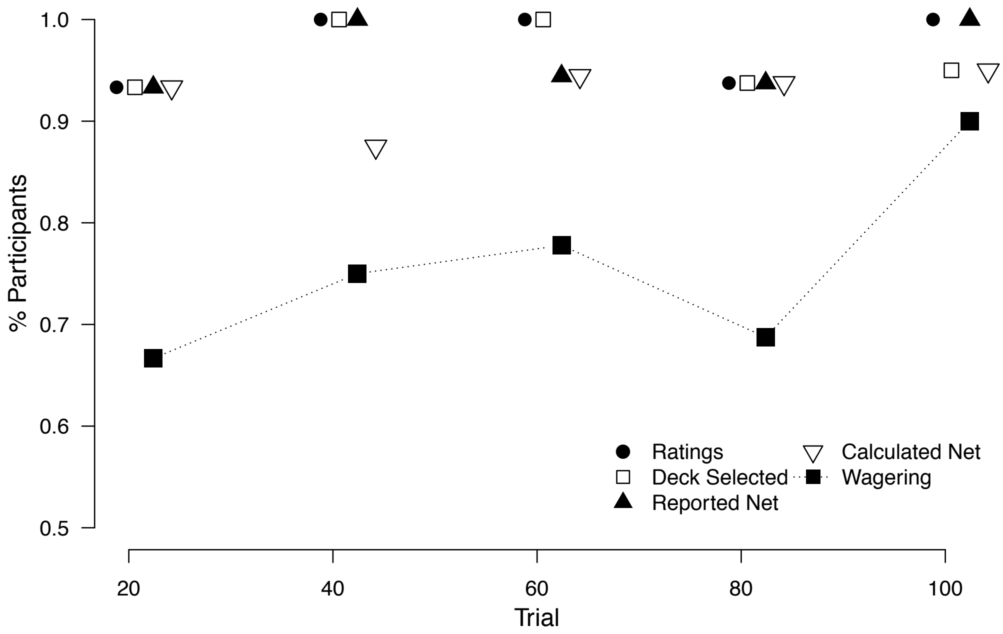
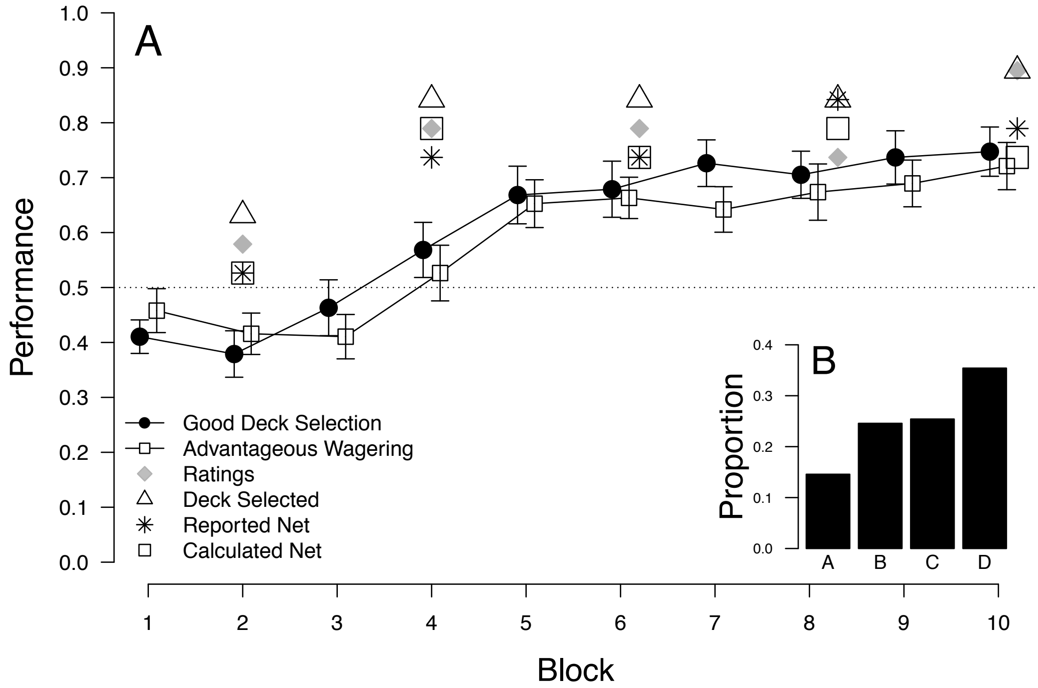
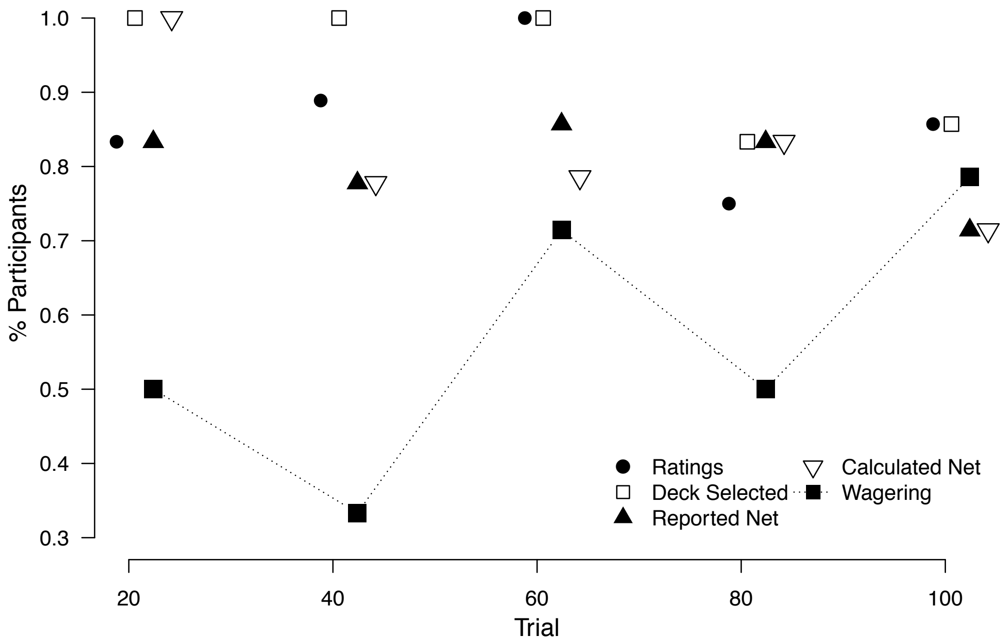

1.0
0.9
0.8
0.7
0.6
0.5
% Participants
20
40
60
80
100
Trial
Ratings
Deck Selected
Reported Net
Calculated Net
Wagering

Figure 7



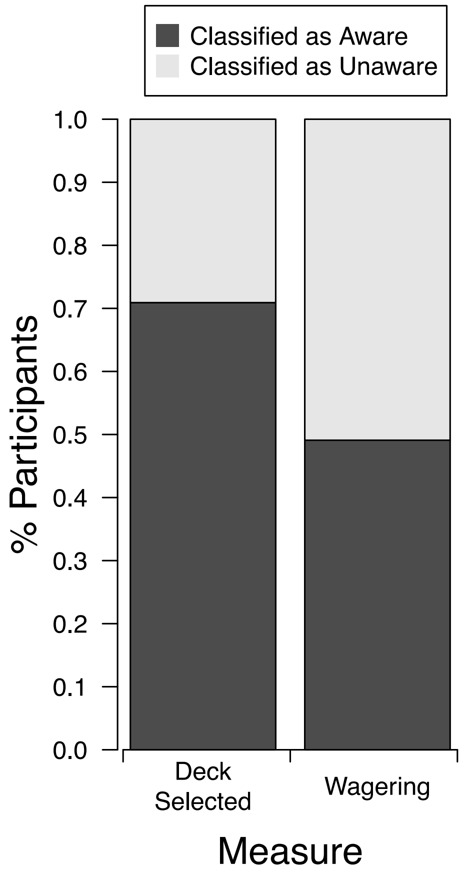
A
B
Performance
Block
Proportion
Good Deck Selection
Advantageous Wagering
Ratings
Deck Selected
Reported Net
Calculated Net
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
2
3
4
5
6
7
8
9
10
0.4
0.3
0.2
0.1
0.0
A
B
C
D

Figure 8



1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
% Participants
20
40
60
80
100
Trial
Ratings
Deck Selected
Reported Net
Calculated Net
Wagering

Figure 9


Classified as Aware
Classified as Unaware
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
% Participants
Deck Selected
Wagering
Measure