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Domain Knowledge and Hindsight Bias among Poker Players

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ABSTRACT

Hindsight bias occurs when individuals believe that events were more predictable after they have occurred than they actually were before they occurred. Although hindsight bias is a well-studied phenomenon, few studies have examined the role of expertise in this bias. Two experiments investigated the relation between the magnitude of hindsight bias and self-reported poker expertise (Experiment 1) and assessed poker knowledge (Experiment 2). In Experiment 1, self-rated poker expertise was negatively correlated with hindsight bias. Experiment 2 employed memory and hypothetical hindsight conditions and found that poker knowledge was negatively correlated with hindsight bias in the memory condition, but unrelated to hindsight bias in the hypothetical condition. These results help elucidate the role of expertise in hindsight bias and provide additional support for the separate components view, which claims there are different forms of hindsight bias that are differentially affected by certain factors. Domain knowledge appears to be one of such factors. Copyright © 2013 John Wiley & Sons, Ltd.

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Hindsight bias occurs when individuals believe that events were more predictable after they have occurred than the events actually were before they occurred. Hindsight bias is a robust and well-studied phenomenon. Since the phenomenon was first demonstrated (Fischhoff, 1975; Fischhoff & Beyth, 1975), hindsight bias has been the subject of over 800 scholarly publications (Roese & Vohs, 2012). It has recently been argued that the term is used to describe three separate but related phenomena, which are termed components of hindsight bias (Blank, Nestler, von Collani, & Fischer, 2008). The *memory distortion* component of hindsight bias occurs when individuals make judgments, receive feedback, and recall their judgments as having been closer to the feedback than they actually were (i.e., memory for previous predictions is distorted by the feedback). The *inevitability* component occurs when individuals who know outcomes claim that the outcomes were more probable than they actually were (i.e., known outcomes appear inevitable). Finally, the *foreseeability* component occurs when individuals claim that they would have predicted known outcomes more accurately than they actually could (i.e., known outcomes appear predictable). There is accumulating evidence that these three components are dissociable. Factors such as retention interval, explanatory ease, self-relevance, mood, and surprise in outcomes differentially affect the three hindsight bias components (Blank & Nestler, 2006; Blank et al., 2008; Blank & Peters, 2010; Nestler, Blank, & Egloff, 2010; Nestler & Egloff, 2009). Furthermore, these components may arise from different processes and result in different consequences (e.g., Roese & Vohs, 2012).

There are two common approaches examining hindsight bias (e.g., Pohl, 2007). In *memory designs*, participants make judgments, receive feedback, and recall their original judgments (OJ). Hindsight bias is considered to occur when recalled judgments (ROJ) are closer to the feedback than the OJs were. For example, if a participant is asked, “How many countries are in Europe”, responds, “35”, and later learns there are 45 countries in Europe, hindsight bias is present if the participant recalls the OJ as having been closer to 45 than it actually was. Memory designs, then, assess the memory distortion component of hindsight bias. In *hypothetical designs*, participants are provided with feedback and are asked to make a judgment as if they had not been provided with the feedback. In between-subjects hypothetical designs, hindsight bias occurs when judgments from participants provided with feedback are closer to the feedback than judgments from participants not provided with feedback. For example, imagine that some participants are told there are 45 countries in Europe and asked how many countries they thought were in Europe before they were given that number, whereas other participants are simply asked how many countries are in Europe. If the first group’s response is closer to 45 than the second group, there is evidence of hindsight bias. In within-subject hypothetical designs, participants are provided with feedback on some trials but not on others. Hindsight bias occurs when judgments are closer to feedback in trials in which it is provided than to what the feedback would have been in trials in which it was not provided. Hypothetical designs assess the inevitability or foreseeability components of hindsight bias, depending on whether the questions focus on the likelihood of an outcome (inevitability) or what the participant would have known in the absence of feedback (foreseeability).

Although hindsight bias is a widely studied phenomenon, few studies have examined individual differences in this bias (Musch & Wagner, 2007). An early study found that hypothetical and memory hindsight biases were positively correlated across participants, and that a combined memory and hypothetical hindsight bias index was positively correlated with social desirability and motivation for predictability (Campbell & Tesser, 1983). However, the use of this combined index leaves unclear the specific relations between these individual differences and the different components

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of hindsight bias. A later study overcame this limitation and found that hypothetical hindsight was positively correlated with social desirability and impression management, whereas memory hindsight was positively correlated with dogmatism and conscientiousness, illustrating that different factors affect the memory distortion and foreseeability components of hindsight bias (Musch, 2003).

Several relationships between cognitive abilities and hindsight bias have also been demonstrated. For example, field dependence should be related to hindsight bias because people who perform well on field dependence tasks likely possess greater cognitive restructuring ability, which should enable them to separate OJs and learned outcomes (Davies, 1993). Indeed, individuals who performed well on field dependence tasks have demonstrated smaller hindsight bias in both hypothetical (Davies, 1993; Musch, 2003) and memory designs (Davies, 1992, 1993). Results of another hypothetical design revealed that the magnitude of hindsight bias was negatively related to a cognitive ability composite, which included performance on Raven's matrices, a comprehension measure, and total Scholastic Assessment Test score (Stanovich & West, 1998). Additionally, working memory capacity was negatively correlated with hindsight bias in a memory design (Calvillo, 2012). Finally, working memory load may increase memory distortion (Calvillo, 2012), whereas larger working memory loads may decrease the inevitability component of hindsight bias (Nestler, Blank, & von Collani, 2008). These studies show that cognitive abilities affect hindsight bias components, and may do so differentially.

Expertise is related to cognitive ability (e.g., Sternberg, 1998) and may also affect the magnitude of hindsight bias. An early meta-analysis reported that hindsight bias is smaller in studies with experts than in studies with novices (Christensen-Szalanski & Willham, 1991), although a more recent meta-analysis using a more restrictive definition of expertise found no such difference (Guilbault, Bryant, Brockway, & Posavac, 2004). These meta-analyses, however, compare studies with expert participants to studies with novice participants; very few studies have directly compared the hindsight bias between experts and novices. Most of the limited body of evidence available suggests an inverse relation between expertise and hindsight bias. Using a hypothetical design, more experienced physicians were found to be less biased by outcome knowledge than less experienced physicians when making diagnoses, particularly in more difficult cases (Dawson et al., 1988). Similarly, expert baseball players displayed a smaller hindsight bias than novices in recollecting the predicted outcomes of their swings in a memory design (Gray, Beilock, & Carr, 2007). A memory design computer simulation of hindsight bias demonstrated that there was a smaller hindsight bias among people with more domain-specific knowledge (Hertwig, Fanselow, & Hoffrage, 2003), whereas one hypothetical design study (described by Musch & Wagner, 2007) showed that chocolate experts demonstrated a *larger* hindsight bias than novices when judging the amount of cocoa in a piece of chocolate, and another showed that self-rated wine knowledge was unrelated to hindsight bias in judgments about the sweetness of wine (Pohl, Schwarz, Sczesny, & Stahlberg, 2003). These conflicting findings suggest that additional research on the role of expertise in hindsight bias (in particular, its relation to different components of hindsight bias) is needed.

The game of poker provides an ideal context to examine the role of expertise in hindsight bias. Poker players must make numerous judgments based in large part on perceived likelihoods, and success in poker depends in part on making these judgments in an unbiased manner. Moreover, because poker (and particularly the variation of poker called Texas Hold 'em) has recently risen in popularity among college students (Griffiths, Parke, Wood, & Rigbye, 2010; McComb & Hanson, 2009; Shead, Hodgins, & Scharf, 2008; Wood, Griffiths, & Parke, 2007), players with a wide range of expertise are readily available. Poker expertise is domain-specific and subsumes a variety of abilities and skills (Sklansky & Miller, 2006). Last, poker's popularity in both casino and recreational environments (Croson, Fishman, & Pope, 2008) makes the game itself an important topic of the study. The goal of the present research, then, was to examine hindsight bias among poker players of varying expertise. Specifically, this study examined the role of poker expertise (both self-rated and assessed) in both memory and hypothetical hindsight designs.

EXPERIMENT 1: HINDSIGHT BIAS AND SELF-REPORTED POKER EXPERTISE

In Experiment 1, participants reported their poker-playing expertise and made two sets of judgments about the likelihood of winning various poker hands. One set of judgments was made in foresight (i.e., before the outcome of the hand—winning or losing—was known), and one was made in hindsight (i.e., after the outcome was known). Based on the literature on expertise and hindsight bias in memory designs (e.g., Gray et al., 2007), we predicted that participants' hindsight judgments would be biased by the provided outcome and that there would be a negative relationship between hindsight bias and self-reported expertise. Finally, because negative outcomes may trigger sensemaking, negative outcomes show larger hindsight bias than positive outcomes (e.g., Roese & Olson, 1996; Schkade & Kilbourne, 1991). Thus, we predicted that hindsight bias would be greater after a losing hand than after a winning hand.

Method

Ninety-eight participants (75.5% men) were recruited by snowball sampling and from psychological research websites: we invited known poker players to participate and asked them to send the invitation to other poker players. All participants were self-identified poker players. The age and poker experience of the sample are presented in Table 1. There was no incentive for participation.

Data were collected via the Internet. Participants first reported how many years they had been playing poker and how many hours they play poker in the average week. They then rated their poker knowledge, skills, and winnings compared with the average poker player, using a 7-point Likert

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Table 1. Descriptive statistics for age, poker experience and expertise, hindsight index, judgment error, and number of exact foresight judgment recollections in Experiment 1

	Min	*Max*	*M*	*SD*
Age	18	53	24.32	6.96
Years Playing Poker	0	30	6.07	4.85
Hours per Week Playing Poker	0	30	5.7	7.17
Poker Knowledge[a]	1	7	4.35	1.33
Poker Skills[a]	1	7	4.37	1.37
Poker Winnings[a]	1	7	4.38	1.41
Hindsight Bias Index	−9.25	20.63	2.34	5.15
Mean Judgment Error[b]	1.05	37.50	11.62	6.23
Exact Recollection of Foresight Judgment[c]	0	8	1.79	1.56

[a]Poker knowledge, skills, and winnings were self-rated on a scale of 1 to 7, [b]Mean judgment error is the average deviation of a foresight judgment from the correct judgment, [c]Exact recollection of foresight knowledge is to the number of the eight hindsight judgments that exactly matched the foresight judgments

scale anchored at 1 (*far below average*) and 7 (*far above average*), with the scale midpoint labeled *average*. Next, participants made the first set of poker judgments, which consisted of 14 trials. The trials included of an arrangement of cards that resembled Texas Hold ‘em hands. In Texas Hold ‘em, each player is initially dealt two private cards (termed *hole cards*). Each player places a bet based on the strength of these two cards. After this round of betting, three public “community” cards, available for use by all players, are dealt (termed *the flop*) onto the middle of the table. Players bet again based on the strength of these five cards (their two private and three public). Another community card is dealt (termed *the turn*), followed by another round of betting; then, a final community card is dealt (termed *the river*) and is followed by a final round of betting. Players who remain in the game (i.e., have not folded/surrendered their hands in response to previous bets) compose the best five card hand from their two hole cards and five community cards. The best five card hand, scored in accordance with traditional poker hand rankings, wins the money that was wagered on the hand by all players. Note that, because the hand develops in stages, the most promising starting hand (the best hole cards) is not always the best hand once all community cards have been dealt.

In each of the 14 trials in the first set, participants made judgments that are similar to those made while playing Texas Hold ‘em. They were presented with two pairs of hole cards. One pair was labeled *your hand*, and the other was labeled *opponent’s hand*. There was also an area of the screen labeled *community cards*, which showed where the five community cards would be dealt if the hands were played to completion. There were no actual community cards in the first set of trials. Participants judged which hole cards were more likely to win, and the likelihood (on a scale of 0–100%) of their hole cards winning if the hands were played to completion (i.e., if the community cards were dealt). The hole cards used in this experiment were selected such that the actual likelihood of a participant’s hand beating the opponent’s ranged from 20 to 80% with an equal number of hands favoring the participant and the opponent. Objective likelihoods were determined using an online calculator (http://www.cardplayer.com/poker-tools/odds-calculator/texas-holdem). Because actual likelihoods are dependent on several factors, the number of possible outcomes is quite large. Thus, online calculators simulate thousands of hands to approximate likelihoods rather than completing brute force calculations. This first set of trials served as foresight judgments, because participants do not have the knowledge of the hands’ outcome (i.e., they did not yet know which hand would ultimately win).

The second set of poker judgments consisted of eight trials. These trials also contained two pairs of hole cards (one labeled *your hand* and one labeled *opponent’s hand*), but also contained the five community cards, indicating that the hands had been played to completion. These eight trials contained starting hands that were identical to eight of the trials that had been made in foresight in the first set. Four trials had a positive outcome (i.e., the community cards indicated that the participant’s hand won) and another four trials had a negative outcome (i.e., the community cards indicated that the participant’s hand lost), and the outcomes were independent of initial probabilities of the hole cards winning (i.e., high, medium, and low-probability hole cards won and lost). Participants were not informed that the trials in the second set were identical to a subset of the trials in the first set. Participants reported which hand won (theirs or their opponent’s), which starting hand had been more likely to win before any community cards were dealt, and the likelihood of their hand winning before the community cards were dealt (on a scale of 0–100%). They were not instructed to recall their judgments from the first set. These likelihood judgments were made in hindsight, because participants had the knowledge of the outcome of the hand (i.e., they now knew which hand ultimately won).

Results

Participants’ responses to the poker knowledge, skills, and performance questions are presented in Table 1. To assess the validity of these self-report measures of expertise, we analyzed the relationship between these measures and performance on the first set of poker judgments. The mean judgment error for the first set of 14 judgments was calculated for each participant by averaging the absolute value of the difference between the participant’s judgment (OJ), and the actual likelihood of having the winning hand if played to completion on each trial (correct judgment: CJ).

$$\frac{\sum_{i=1}^{14} |\mathrm{OJ}_i - \mathrm{CJ}_i|}{14} \quad (1)$$

The mean judgment error across to all participants is presented in Table 1. As shown in Table 2, judgment error was negatively correlated with all three measures of expertise, demonstrating that participants who rated themselves higher in poker knowledge, skills, and performance indeed made more accurate poker judgments than participants who rated themselves lower on these measures.

To assess hindsight bias, we conducted a two-way repeated measures analysis of variance examining the effects

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Table 2. Correlations of measures of self-rated poker expertise, hindsight index, judgment error, and number of exact foresight judgment recollections in Experiment 1

	1	2	3	4	5
1. Poker Knowledge[a]	—				
2. Poker Skills[a]	.83***	—			
3. Poker Winning[a]	.76***	.81***	—		
4. Hindsight Bias Index	−.21*	−.22*	−.22*	—	
5. Mean Judgment Error[b]	−.21*	−.26**	−.29**	.27**	—
6. Foresight Recollection[c]	.24*	.31**	.29**	−.14	−.27**

*$p < .05$, **$p < .01$, ***$p < .001$, [a]Poker knowledge, skills, and winnings were self-rated on a scale of 1–7, [b]Mean judgment error is the average deviation of a foresight judgment from the correct judgment, [c]Exact recollection of foresight knowledge is to the number of the eight hindsight judgments that exactly matched the foresight judgments

of outcome [positive (i.e., the participant's hand winning) or negative (i.e., the participant's hand losing)] and outcome knowledge (foresight or hindsight) on participants' judgments of the likelihood of their hand winning. Hindsight bias is present when participants' judgments are influenced by a known outcome. Consequently, with positive outcomes, the hindsight bias is present if hindsight judgments are greater than foresight judgments, but with negative outcomes, the hindsight bias is present when hindsight judgments are *less* than foresight judgments. Therefore, the hindsight bias should lead to an interaction between outcome and outcome knowledge. The mean judgments for all four conditions are presented in Table 3. The analysis of variance revealed a main effect of outcome, $F(1,\ 97) = 5.87$, $p = .017$, $\eta_p^2 = .06$, no effect of outcome knowledge, $F(1,\ 97) = 0.85$, $p = .358$, $\eta_p^2 = .01$, and an interaction, $F(1,\ 97) = 20.23$, $p < .001$, $\eta_p^2 = .17$. As predicted, simple effects tests revealed that hindsight judgments were greater than foresight judgments when the outcome was positive, $t(97) = 2.20$, $p = .030$, $d = .22$, and hindsight judgments were less than foresight judgments when the outcome was negative, $t(97) = 3.66$, $p < .001$, $d = .37$. The magnitude of hindsight bias for losing hands did not significantly differ from the magnitude for winning hands, $t(97) = 0.92$, $p = .358$, $d = 0.14$.

To examine individual differences in the hindsight bias, a hindsight bias index was calculated for each participant by averaging the increase between foresight OJ and hindsight ROJ judgments for the four positive outcome trials and the decrease between foresight and hindsight judgments for the four negative outcome trials. For positive outcomes,

$$\text{Absolute Shift Index} = \text{ROJ-OJ} \quad (2a)$$

whereas for negative outcomes,

$$\text{Absolute Shift Index} = \text{OJ-ROJ} \quad (2b)$$

Table 3. Mean likelihood judgments by outcome and outcome knowledge in Experiment 1

	Outcome Knowledge					
	Foresight		Hindsight		Difference	
Outcome	*M*	*SD*	*M*	*SD*	*M*	*SD*
Positive	46.85	6.65	48.63	5.27	1.78	8.00
Negative	50.90	6.20	48.00	6.84	2.90	7.84

This measure is an absolute shift index (Pohl, 2007), with values greater than zero indicating a hindsight bias and larger values indicating a greater magnitude of hindsight bias. The mean hindsight bias index, presented in Table 1, was significantly greater than zero, $t(97) = 4.50$, $p < .001$, $d = .45$. We examined the relationships between participants' poker expertise, judgment error, and their hindsight bias index. Participants' self-reported poker knowledge, skill, and winning were used as a measure of poker expertise. Bivariate correlations between all measures are presented in Table 2. The three expertise measures were negatively correlated with the hindsight bias index, and the hindsight index was positively correlated with judgment error.

One explanation for the negative correlation between the hindsight bias and expertise is that experts' superior memory for judgments made in their domain of expertise (e.g., Chase & Simon, 1973) leads to more accurate recollection of foresight judgments, thus reducing the biasing effect of outcome knowledge. To test this possibility, we counted the number of hindsight judgments that perfectly matched a corresponding foresight judgment for each participant. These counts could range from 0 to 8, and the descriptive statistics for this measure are presented in Table 1. The three expertise measures were positively correlated with the number of matching foresight-hindsight judgments, and the number of matching foresight-hindsight judgments was not significantly correlated with the hindsight index; experts did in fact have superior memory of their judgments, but this memory advantage, alone, did not appear to account for the reduction in hindsight bias.

To increase the reliability of the self-reported expertise measures, we took each participant's average response to these three items to create a single expertise index. This expertise index ($M = 4.36$, $SD = 1.28$) was negatively correlated with the hindsight index, $r(96) = -.24$, $p = .020$, negatively correlated with judgment error, $r(96) = -.27$, $p = .007$, and positively correlated with the number of matching foresight-hindsight judgments, $r(96) = .30$, $p = .002$.

Discussion

The results of Experiment 1 demonstrate that participants' hindsight judgments are biased by a provided outcome, consistent with a large body of the previous research on hindsight bias (e.g., Fischhoff, 1975). When they were shown that their hands had won, participants judged the

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likelihood of their hole cards winning as greater than they had in foresight; when they were shown their hands lost, they judged the likelihood of their hole cards winning as less than they had in foresight. Hindsight bias following a negative outcome was not significantly greater than after a positive outcome, as had been found in previous studies (e.g., Roese & Olson, 1996; Schkade & Kilbourne, 1991), although the trend was in the predicted direction. Perhaps losing a simulated poker hand in which they have not actually risked any money was insufficiently important to participants to create the difference in hindsight bias for the two outcomes. The negative relationships between the hindsight bias and the three self-reported measures of expertise are consistent with extant research demonstrating a smaller hindsight bias among experts (e.g., Gray et al., 2007).

One limitation of Experiment 1 was its reliance on self-reported expertise. It may be the case that, for example, participants' ratings of their knowledge, skills, and performance are subject to similar biases as their poker-related likelihood judgments. The above-average effect (i.e., the tendency for individuals to rate themselves as above average on most characteristics), and hindsight bias may be different varieties of self-serving biases that result from affect regulation (e.g., Roese & Olson, 2007). That self-reported expertise measures were negatively correlated with the magnitude of errors made in the first set of poker judgments (i.e., participants who rated themselves higher on the three expertise measures made more accurate judgments) supports the validity of self-ratings of poker expertise. Nevertheless, it is preferable to use a more objective measure of expertise.

Another limitation of Experiment 1 is the hindsight design. It resembled a memory design in that participants made foresight judgments, received feedback, and then made hindsight judgments. However, during the hindsight judgments, participants were not instructed to recall their original foresight judgments, and they were not informed that the hands were the same as those made during the foresight phase. They were instructed to make judgments that they would have made if they had not been informed of the outcome of the hand. The design was essentially a memory design with a hypothetical instruction. Similar designs have been used in hindsight bias studies (e.g., Fessel, Epstude, & Roese, 2009; Tykocinski, 2001), but it is unclear which component of hindsight bias is assessed by this approach. Because expertise may affect hindsight bias differently in the two designs—specifically, expertise may increase hindsight bias in hypothetical designs and decrease hindsight bias in memory designs (Roese & Vohs, 2012)—examining the impact of poker expertise on specific components of hindsight bias requires the use of traditional memory and hypothetical designs.

EXPERIMENT 2: HINDSIGHT BIASES AND ASSESSED POKER KNOWLEDGE

In Experiment 2, we attempted to overcome the limitations of Experiment 1 by using an objective measure of poker expertise and by employing traditional memory and hypothetical conditions. We also revised the poker judgment task to make it more similar to real poker judgments and altered the type of feedback provided to participants to be more consistent with extant hindsight bias studies. All participants made a set of 20 foresight judgments, completed a poker knowledge questionnaire (adapted from Meinz et al., 2012), recalled 10 of their OJs without feedback, recalled the other 10 after receiving the CJs, were given the CJs to 10 additional trials, and were asked what judgment they would have made if they had not been given the CJ. The poker knowledge questionnaire provides an objective measure of poker expertise and has been demonstrated to predict performance on poker tasks (Meinz et al., 2012). The design allows for the testing of hindsight bias in memory and hypothetical conditions in the same individuals. Finally, the 10 trials in which participants recalled their OJs without feedback were included to rule out hindsight bias resulting from extreme foresight judgments regressing to the mean in hindsight (Pohl, 2007).

We predicted that participants' ROJs would be closer to the provided feedback than were their OJs (i.e., a memory distortion hindsight bias in the memory condition). We also predicted that hypothetical judgments made after feedback would be closer to the feedback than their OJs were (i.e., a forseeability hindsight bias in the hypothetical condition), and, based on the previous findings (Campbell & Tesser, 1983; Musch, 2003), we predicted that these two hindsight biases would be positively correlated across participants. Because experts have superior memory for domain-relevant information, and they have greater ego involvement in domain-relevant tasks, experts may show smaller hindsight bias in memory designs, but larger hindsight bias in hypothetical designs (Roese & Vohs, 2012). Therefore, we predicted that the hindsight index from the memory trials would be negatively correlated with poker knowledge (because experts may better recall or reconstruct their foresight judgments), whereas the hindsight index from the hypothetical trials would be positively correlated with poker knowledge (because experts may want to appear more knowledgeable than they actually are).

Method

Seventy one participants (60.6% men) were recruited through Amazon's Mechanical Turk and were compensated with a small amount of money that was not contingent on performance. All participants reported having familiarity with Texas Hold 'em. The age and poker experience of the sample are presented in Table 4.

Data were collected via the Internet. As in Experiment 1, participants first reported how many years they had been playing poker, how many hours they play poker in the average week, and rated their poker knowledge, skills, and winnings compared with the average poker player, using a 7-point Likert scale anchored at 1 (*far below average*) and 7 (*far above average*), with the scale midpoint labeled *average*. Participants then made the first set of poker judgments, which consisted of 20 trials. These trials asked participants to judge the likelihood of a pair of hole cards winning in a game with one opponent whose cards are unknown to the participant. These are more realistic judgments than those

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Table 4. Descriptive statistics for age, poker experience and self-rated expertise, poker knowledge, and hindsight indices in Experiment 2

	Min	*Max*	*M*	*SD*
Age	18	67	30.27	9.76
Years Playing Poker	0	50	7.89	7.91
Hours per Week Playing Poker	0	15	2.77	2.92
Self-Rated Poker Knowledge[a]	1	7	4.08	1.50
Self-Rated Poker Skills[a]	1	7	4.06	1.49
Self-Rated Poker Winnings[a]	1	7	4.06	1.50
Assessed Poker Knowledge[b]	8	37	24.37	7.92
Memory Hindsight Bias Index	−24.70	24.50	2.86	7.03
Hypothetical Hindsight Bias Index	−6.05	24.89	3.94	5.52

[a]Poker knowledge, skills, and winnings were self-rated on a scale of 1–7, [b]Assessed poker knowledge is based on performance on the 38-item poker knowledge questionnaire

made in Experiment 1, because in actual poker games, players must judge the strength of their hands without knowing opponents' cards. The actual likelihoods ranged from 34 to 80% that the participant's hand would beat an unknown hand. These likelihoods were taken from an online table (http://wizardofodds.com/games/texas-hold-em/2-player-game/).

Participants then completed 38 questions taken from a 61-item poker knowledge measure created by Meinz et al. (2012). These questions assessed knowledge of poker terminology and rules. The 38 items were selected, through consultation with a professional poker player, as being the most unambiguous and most likely to distinguish between poker experts and novices (S. Smith, personal communication, July 18, 2012). After completing the poker knowledge questionnaire, participants recalled 10 of the 20 OJs. Next, they were provided with the CJs (the actual likelihoods), and they were asked to recall each of the remaining 10 OJs. Finally, participants were provided with correct likelihoods for 10 additional pairs of hole cards and asked what their judgments would have been for the likelihood of each hand winning if they had not been provided with the actual likelihood. The three sets of 10 trials were closely matched for actual likelihoods of winning. The order of these tasks was fixed (in the order described previously) for all participants, and the trials within each task were randomized for each participant. Although the order of the tasks may influence the magnitude of hindsight bias, using a fixed order avoided adding variance to hindsight indices that could not be explained by performance on the poker knowledge questionnaire. Participants took about 15 min to complete all of the tasks.

Results

Participants' responses to the self-reported poker knowledge, skills, and performance questions, and their performance on the poker knowledge questionnaire are presented in Table 4. The self-rated measures of poker expertise used in Experiment 1 were all significantly positively related to performance on the poker knowledge questionnaire used in Experiment 2. These correlations are presented in Table 5.

To assess the magnitudes of memory distortion and foreseeability hindsight biases, we calculated a proximity index for the memory and hypothetical conditions of this experiment. Using an absolute shift index is recommended when feedback is identical to endpoints on a scale, like a hand winning or losing (as in Experiment 1), whereas using a proximity index is recommended when feedback is in the form of continuous values, as in the present experiment (Pohl, 2007). The proximity index is the absolute difference between an OJ and a feedback value of CJ minus the absolute difference between the ROJ and the feedback value of CJ.

$$\text{Proximity Index} = |\text{OJ} - \text{CJ}| - |\text{ROJ} - \text{CJ}| \quad (3)$$

For example, if a participant judged the likelihood of a given hand winning at 60%, the actual likelihood is 70%, and the participant recalled the OJ as 65%, the proximity index would be 5 (i.e., $|60–70|–|65–70| = 5$). This index is the difference between the magnitude of participants' errors in foresight and the magnitude of their errors in hindsight. A proximity index greater than zero indicates hindsight bias, with greater indices indicating more bias.

A proximity index was computed for each trial and each participant's memory, and hypothetical condition trials were aggregated by taking the means for these conditions. In the memory condition, the proximity index for the 10 OJs recalled without feedback ($M = 1.18$, $SD = 4.91$) was subtracted from the proximity index from the 10 OJs recalled with feedback ($M = 4.03$, $SD = 6.30$) to control for regression effects (as suggested by Pohl, 2007). As predicted, the resulting proximity index for the memory condition, presented in Table 4, was significantly greater than zero, $t(70) = 3.43$, $p = .001$, $d = 0.41$, demonstrating the presence of memory distortion.

For the hypothetical condition, the proximity index was computed in a similar manner. For each of the 10 hypothetical trials, the absolute difference between the participants' judgments and the CJs was computed. The mean of these differences was subtracted from the mean of the absolute

Table 5. Correlations of measures of self-rated poker expertise, poker knowledge, and hindsight indices in Experiment 2

	1	2	3	4	5
1. Self-Rated Poker Knowledge[a]	—				
2. Self-Rated Poker Skills[a]	.87***	—			
3. Self-Rated Poker Winning[a]	.82***	.83***	—		
4. Assessed Poker Knowledge[b]	.42***	.48***	.39**	—	
5. Memory Hindsight Bias	−.15	−.14	−.07	−.29**	—
6. Hypothetical Hindsight Bias	−.11	−.07	−.12	.00	.43***

$^{**}p < .01$, $^{***}p < .001$, [a]Poker knowledge, skills, and winnings were self-rated on a scale of 1–7, [b]Assessed poker knowledge is based on performance on the 38-item poker knowledge questionnaire

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difference between the 20 OJs and CJs in the foresight condition. The proximity index compares the magnitude of hypothetical errors in hindsight with the magnitude of actual errors in foresight. As predicted, the mean proximity index for the hypothetical condition, presented in Table 4, was significantly greater than zero, $t(70) = 6.01$, $p < .001$, $d = 0.71$.

To test the predictions that poker knowledge is negatively related to hindsight bias in the memory condition and positively related to hindsight bias in the hypothetical condition, correlational analyses were conducted. The bivariate correlations between measures are provided in Table 5. As predicted, poker knowledge was negatively correlated with hindsight bias in the memory condition. However, poker knowledge was not significantly related to hindsight bias in the hypothetical condition. Furthermore, the two proximity indices were positively correlated with each other.

Discussion

In Experiment 2, participants demonstrated hindsight bias in both the memory and hypothetical conditions. Their memory for their OJs was distorted by the provided feedback, and their responses to hypothetical questions were closer to CJs than their responses in trials without feedback. Similar to previous studies, hindsight bias in the two conditions was positively correlated across participants (Campbell & Tesser, 1983; Musch, 2003). Finally, participants' performance on the poker knowledge questionnaire was negatively correlated with hindsight bias from the memory condition as predicted by others (Roese & Vohs, 2012) and reported in a computer simulation (Hertwig et al., 2003). However, there was no significant relationship between poker knowledge and hindsight bias in the hypothetical design. We review these results further in the General Discussion.

One potential limitation of Experiment 2 was the use of Amazon's Mechanical Turk to recruit participants. Several studies, however, have reported that many judgment and decision making results obtained in the laboratory replicate using Mechanical Turk (Buhrmester, Kwang, & Gosling, 2011; Horton, Rand, & Zeckhauser, 2011; Paolacci, Chandler, & Ipeirotis, 2010)

GENERAL DISCUSSION

The results of the present study demonstrate that poker players' poker judgments are biased by the provided feedback. Hindsight bias, in both memory and hypothetical designs, was evident in this context. Self-reported poker expertise was negatively correlated with hindsight bias in Experiment 1, and assessed poker knowledge was negatively correlated with the memory distortion component and unrelated to the foreseeability component of hindsight bias in Experiment 2. The results of the memory design potion of Experiment 2 were similar to those of Experiment 1. This similarity provides some validation of Experiment 1's self-report measures of expertise and also suggests the design of Experiment 1 shares more similarity with a memory design than a hypothetical design. The results of the present study add to the sparse literature on the effects of expertise in hindsight bias (Dawson et al., 1988; Gray et al., 2007; Hertwig et al., 2003). The results of Experiment 2 are consistent with the separate components view of hindsight bias (e.g., Blank et al., 2008). The relationship between expertise and hindsight bias being different for different hindsight components has been previously predicted (Roese & Vohs, 2012), but the present study, to our knowledge, is the first to test this prediction.

One limitation of the present studies is the difficulty in determining the actual poker expertise of our sample in an absolute sense. All participants reported familiarity with Texas Hold 'em, but this was the only prerequisite for participation; thus, participants could have ranged from non-players to professionals. The results of our study may have been different if we sampled more or less experienced poker players (i.e., shifting the mean level of expertise). An inverted U-shaped relationship between expertise and hindsight bias has been posited, in which bias increases from low to moderate levels of expertise and then decreases from moderate to high levels of expertise (Knoll, 2009). Specifically, Knoll (2009) suggests that novices and experts may show less hindsight bias than those with moderate levels of expertise because novices realize that they do not possess domain knowledge and, similarly, experts are better at recognizing the limits in their knowledge than those with moderate levels of expertise. If expertise and hindsight bias have an inverted U-shaped relationship, the location of the range of poker expertise in the present study would affect the relationship between poker expertise and hindsight bias. It has been suggested that 10 years of deliberate practice may be necessary to become an expert (Ericsson, Krampe, & Tesch-Römer, 1993). The mean number of years playing poker was less than 10 in both of the current studies, suggesting that the majority of our participants were not true poker experts by this standard. Additional research could employ a sample with a wider range of poker knowledge.

The present study examined the memory distortion and foreseeability components of hindsight bias; the inevitability component of hindsight bias should also be explored. Furthermore, the nature of the domain of expertise may be important. Relating hindsight bias to overconfidence, it was suggested that domains that have unambiguous feedback (e.g., chess and weather forecasting) should demonstrate a diminished hindsight bias among experts, whereas domains with more ambiguous feedback (e.g., courtroom judges and clinical psychologists) should not show as strong of an effect of expertise (Roese & Vohs, 2012). Because the game of poker provides continuous, clear feedback, decisions should improve, overconfidence should decrease, and hindsight bias should decrease with poker expertise. Poker decisions have been shown to improve with experience (Germain & Tenebaum, 2011; Liley & Rakow, 2010; Linnet, Gebauer, Shaffer, Mouridsen, & Møller, 2010), although overconfidence appears related to chess expertise but unrelated to poker expertise (Park & Santos-Pinto, 2010).

Although the relation between poker knowledge and memory distortion was significant in the present study, a great deal of variance in memory distortion was unexplained.

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Poker knowledge, using the full version of the questionnaire used in the present study, has been shown to predict performance on poker-related tasks, but working memory capacity explains a significant amount of additional variance (Meinz et al., 2012). This is also true in other domains; working memory capacity explains additional variance in the domain knowledge-performance relationship (Hambrick & Meinz, 2011, for a review of this literature). Working memory capacity has also been demonstrated to predict memory distortion hindsight bias (Calvillo, 2012), implying that some of the variance in memory distortion unexplained by poker knowledge may be the result of individual differences in working memory capacity. Another avenue for additional research is combining domain-specific knowledge and domain-general working memory capacity to explain differences in hindsight bias.

Participants were allowed to respond at their own pace in the present study. Processing speed increases with expertise (e.g., Ericsson & Lehmann, 1996), and chess experts are less affected by time constraints, such as those in Blitz chess, than novices (e.g., Burns, 2004; Calderwood, Klein, & Crandall, 1988). In poker, however, time constraints decrease the difference in the quality of poker decisions made by both experts and novices, particularly those decisions made later in the hand (e.g., after the flop; Germain & Tenenbaum, 2011). Time constraints have also been shown to increase the memory distortion component of hindsight bias (Calvillo, 2013). Additional studies could examine the effect of rapid recollection of OJs after feedback among participants of varying expertise.

Finally, components of hindsight bias could be examined in pathological gambling poker players. This population may show increased hindsight bias (all components), similar to what has been reported among pathological gambling blackjack, roulette, and slot machine players (Baboushkin, Hardoon, Derevensky, & Gupta, 2001). Pathological gambling poker players' poker judgments and decisions have been found to be more biased than those of non-pathological gambling poker players (Linnet et al., 2012), but the hindsight bias has not been examined among pathological poker players.

As poker has recently risen in popularity (Croson et al., 2008), there has been an increase in studies examining poker judgments. Previous studies have identified distorted cognitions among poker players (Mitrovic & Brown, 2009) and the relationships between superstitious beliefs toward poker and personality factors (Brown & Mitchell, 2010). The present study adds to the literature by demonstrating that memory distortion and foreseeability components of hindsight biases exist among poker players, but only memory distortion is related to poker expertise.

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