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Reasoning in the Monty Hall problem: Examining choice behaviour and probability judgements

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This research examined choice behaviour and probability judgement in a counterintuitive reasoning problem called the Monty Hall problem (MHP). In Experiments 1 and 2 we examined whether learning from a simulated card game similar to the MHP affected how people solved the MHP. Results indicated that the experience with the card game affected participants' choice behaviour, in that participants selected to switch in the MHP. However, it did not affect their understanding of the objective probabilities. This suggests that there is dissociation between implicit knowledge gained from the task and the explicit understanding as to why switching was the best strategy. In Experiment 3, the number of prizes and doors were manipulated to examine how participants construed the problem space of the MHP. Results revealed that participants partition the probability judgement to reflect the number of prizes over the number of unopened doors.

Human reasoning does not always adhere to the formal rules of logic (e.g., using expected utility or Bayes theorem). Instead, considerable research has revealed that people often neglect formal rules when deriving solutions to problems (Stanovich, 1999). People often fail to incorporate to base-rate information (e.g., Fischhoff & Bar-Hillel, 1984), fail to adhere to the rules of probability theory (e.g., Hammerton, 1973), and fail to follow rules dictated by expected utility theory (e.g., Lichtenstein & Slovic, 1971). Why do people produce these errors?

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Research on human reasoning and decision making suggests that reasoning errors are often due to errors in performance, computation, and task construal (Arkes, 1991; Stanovich, 1999). Because many of these errors are cognitively based, it is important that we understand the cognitive processes underlying both good and poor reasoning. To the extent that we can begin to understand what cognitive processes underlie reasoning, we can begin to develop methods to help facilitate better reasoning.

In this paper, we examined choice behaviour and probability judgement in a counterintuitive reasoning problem called the Monty Hall problem (MHP), which is named after the host of the popular 1970s game show *Let's Make a Deal* (Selvin, 1975, see also Gardner, 1961, for a variant of MHP with three prisoners). The MHP is intriguing because the solution to the problem requires that the person employ rules of logic that contradict intuition. This property (i.e., that intuition contradicts the rules of logic) makes the problem an especially interesting research tool, because it puts at odds two mechanisms that can be used to make decisions (logic versus intuition). Indeed, prior research on the MHP has revealed that people rarely solve the problem correctly, allowing their intuitions to trump the rules of logic. The purpose of the present research was to explore the cognitive processes underlying how people attempt to solve the MHP and to explore the factors that contribute to people's proclivity to rely on their intuitions to solve the problem.

THE MONTY HALL PROBLEM

The Monty Hall problem (MHP) is typically construed as a game show scenario with three doors: Behind one of the doors is a valuable prize (e.g., new car) and behind each of the other doors is an undesirable prize (e.g., goat). A contestant is asked to select one of three doors (e.g., door 1), and then the honest host opens one of the unselected doors to reveal that the car is not behind that door (e.g., door 2). After revealing the contents of the door, the host gives the contestant the option to stay with the initial selection (door 1) or switch to the other unopened door (door 3). Note that the host is aware of the location of the prize and will never open the contestant's door or the door containing the valuable prize.

Most people estimate the probability of winning the prize as the same regardless of whether they stay or switch doors. However, assessing that there is an equal (.50) chance of winning the prize regardless of the decision to stay or switch is mathematically incorrect. In fact, the probability that the prize is behind the initially selected door is still .33, but is .67 for the unselected and unopened door (Bar-Hillel, 1989; Gillman, 1992; vos Savant, 1996). The three doors can be considered a set, which can be partitioned into two subsets (1) subset A: the door selected by the contestant, and (2) subset B: the two doors not selected by the contestant (see Granberg, 1999a, for pictorial depiction of the sets associated with the MHP). The probability that the prize is in subset A and B is .33 and .67

respectively, and these probabilities remain the same even after the host reveals that one of the doors from subset B is a non-winner. Given that there is now only one door left in subset B, the probability of that door having the prize becomes .67. Clearly, there is a greater chance that the valuable prize is behind the unselected door in this subset. The correct response to the MHP is based on conditional probability, but people are inclined to believe that the door that has been opened is now eliminated (and consequently irrelevant) so the probabilities appear to be equally distributed between the two remaining doors. However, this is not the case, for the opened door remains in the conditional equation. Thus, eliminating one of the doors from subset B does not change the probabilities of the two subsets.

An interesting aspect of the MHP is that although people discern the probabilities as being equal, they have an overwhelming propensity to stay with their initial selection. Thus, it seems that once they have made an initial commitment to one of the three doors (presumably by random choice), they feel more compelled to stay rather than switch. Not only do people judge the probabilities as equal, but they are also highly confident of their response (cf. Falk, 1992). Falk (1992) posits that people might rely, to various degrees, on their intuitions when making choices. Since the mathematically correct solution is *counterintuitive,* this makes the MHP especially difficult.

Although relatively little research has investigated human reasoning involved in solving the MHP, a consistent pattern of results has emerged from the few studies that have been conducted. The first major finding is that very few participants elect to switch (Granberg & Brown, 1995; Platt & Watkins, 1997) despite the fact that switching is the normatively correct response and has a higher probability of winning. For example, Granberg and Brown (1995) found that the majority of participants (84%) stayed with their initial selection. This propensity to stay with the initial door is quite robust, and has been demonstrated across a variety of cultures (e.g., Brazil, China, Sweden, and United States; Granberg, 1999b). However, Page (1998) demonstrated that people are more willing to switch to the other door when presented with 100 doors as compared to 3- and 10-door MHP situations. Perhaps not surprisingly, participants still fail to see that the *probabilities* favour switching (even when they are willing to switch). Platt and Watkins (1997) found that over 93% of respondents believed that the chances of winning the prize was .50 after the host opens the door, even though they had correctly estimated the initial probability to be .33 for their door. Consequently, there are two elements of interest that factor into MHP reasoning: (1) why do people show a propensity to stay, and (2) what factors affect the accuracy of participants' probability judgements.

A fundamental question is whether people can learn that switching is the optimal strategy by playing the MHP repeatedly. In a computer game that simulated the MHP, Granberg and Brown (1995) investigated whether playing successive trials increased participants' ability to understand that switching was the best strategy. The results suggest that participants can learn to switch across trials and switching occurs more often as the incentive (points allotted for winning each trial) increases. Friedman (1998) provided further support that participants can learn to switch across trials in a card game. Additionally, Granberg and Dorr (1998) revealed that participants were willing to switch more often as the number of doors in computer trials increased from three to five to seven. These studies have demonstrated that the switching strategy can be learned by repeatedly playing a simulated game. However, the question remains as to whether people can transfer the knowledge acquired from a simulated game to solve the MHP. Moreover, can people gain an understanding of the probabilistic structure of the game with repeated plays?

The purpose of the present set of studies was to examine reasoning in the MHP. In Experiments 1 and 2 we investigated whether using a similar learning task could debias the reasoning errors commonly found in the MHP. Specifically, we sought to examine whether the degree of similarity between a simulated card game and the MHP would affect participants' ability to transfer their knowledge from the card game to the MHP. In Experiment 3, we examined how varying the number of prizes and doors affected participants' perception of the probabilities involved in the MHP.

OVERVIEW OF EXPERIMENTS 1 AND 2

The main purpose for conducting Experiments 1 and 2 was to investigate whether card-game similarity affects choice behaviour and probability judgements in the MHP. We created two versions of the card game in order to manipulate the similarity between the game and the MHP: a 3-card and a 10-card game. The rules were similar for both the 3-card and 10-card games. The 3-card version consisted of three cards: one ace and two non-ace cards. The participant selected a card, one non-ace card was revealed, and then the participant decided to stay with the initially selected card or switch to the other unselected card. A similar design was used for the 10-card version with one ace and nine non-ace cards. The participant selected a card, and eight non-ace-cards were revealed prior to the participant's decision to stay or switch. The 3-card game simulated the .33: .67 (stay: switch) probabilities of the MHP and the 10-card game simulated .10: .90 (stay: switch) probabilities. The goal of the card games was to train participants to understand that switching is the normatively correct solution. We hypothesised that extensive practice with the card game would allow participants to lean the probabilistic structure of the game and apply it to the MHP. We further hypothesised that a high similarity between the card game and the MHP would facilitate transfer from the card game to the MHP.

There are two components of the game that could be learned by participants. The first component is that switching is the optimal behaviour. We refer to this as gaining a superficial understanding of the problem, for it is possible that one can note that switching is the optimal behaviour, but not fully understand the reason why this is so. The second component of the game that participants might learn is the underlying probability structure of the game. We refer to this as gaining a probabilistic understanding of the problem: If a person gains an understanding of the probabilistic structure of the game, then they have obviously gained insight into *why* switching is better.

In Experiments 1 and 2 we presented the card game and the MHP with four possible conditions: 3-card|3-door, 3-card|10-door, 10-card|10-door, and 10-card|3-door. The 3-card|3-door and 10-card|10-door conditions are congruent in terms of numbers of cards–doors whereas the 3-card|10-door and 10-card|3-door conditions are incongruent between the two tasks. One by-product of manipulating the similarity in terms of number of cards and doors is that it also affects the underlying probabilistic structure of the games. Although switching remains the best strategy regardless of the number of cards or doors, the probabilistic structure of the game is different for the 3-door (.33 stay vs 67 switch) and 10-door (.10 stay vs .90 switch) versions.

EXPERIMENT 1

In Experiment 1 we added another dimension to the card game by manipulating the number of trials in which the player decided to stay or switch. Some participants played the card game and had the opportunity to stay or switch per trial while others made a decision that was effective for five trials. By forcing the participant to use the same decision for several trials, we allowed the participant to witness the outcomes associated with the stay/switch decision. We expected that constraining how often the player made a decision (e.g., one decision effective for five trials) might entice players to invest more cognitive effort in future decisions (cf. Hogarth, Gibbs, McKenzie, & Marquis, 1991) and subsequently use a long-term strategy. Inducing participants to exert more mental effort might facilitate an understanding of the switching strategy and potentially the probabilistic structure of the game. Noting the card trials outcomes in blocks rather than single trials provided the opportunity for the participant to consider the consequences of staying and switching. Thus, we hypothesised that constrained choice participants would select to switch more often than participants who made a decision to stay/switch at each trial. Additionally, we hypothesised that switching performance in the card game would differ for 3-card and 10-card players. Specifically, 10-card game players should begin switching more often from the onset of the game and maintain higher switching percentages across trials than the 3-card game players. The probabilities associated with switching and winning in the 10-card game are more extreme than the 3-card game (.90 for 10-card compared to .66 for 3-card) so, once a player begins the 10-card game, the prominence of the switching strategy is revealed. We do not make the assumption that the player will necessarily understand why switching is better, but that he or she will realise that switching results in a greater number of wins.

Regarding choice behaviour (staying or switching in the MHP), we hypothesised that people would switch more frequently when the numbers of cards and doors were congruent than incongruent. In addition, switching should be greater for the 10-card|10-door condition than the 3-card|3-door condition because the objective probabilities of switching and winning are greater in the 10-card version. In the incongruent case, the 10-card|3-door participants were predicted to transfer the switching strategy more often than by 3-card|10-door participants. The objective probabilities in the 10-card situation favour the switching strategy, so that the 10-card players would experience a greater percentage of switching and winning than the 3-card players, and the exposure to the successful switching strategy in the card game might transfer to the MHP.

Participants who selected to switch in the MHP are hereafter known as *switchers* and those who selected to stay in the MHP are hereafter known as *stickers.* Additionally, we hypothesised that when we examined how MHP *stickers* and *switchers* had played the card game, MHP *switchers* would switch more often in the card game and have greater success associated with switching than *stickers.* If the player in the card game switched and won more frequently than staying, then the player would be more likely to transfer the switching strategy to the MHP due to prior success in the card game. Card game players who stayed would not recognise that switching is advantageous and therefore, in the MHP, should choose to stay.

Regarding participants' probability judgements, we hypothesised that the congruency between the card game and MHP would increase the number of participants who correctly estimated the probabilities in the MHP compared to the incongruent conditions. In the latter case, we expected that fewer people would generate the correct probability due to the fact that the probabilities of the card game would not map onto the probabilities of the MHP.

Method

Participants. Undergraduate students (N= 142) at the College of William & Mary participated in the experiment for course credit.

Design. The experiment design was 2 × 2 × 2 between factorial, consisting of number of cards in the game (3 or 10 cards), choice for card trials (free choice or constrained choice), and number of doors in the MHP (3 or 10 doors). In the free choice manipulation, the participant had the opportunity to select to stay or switch for each card trial. In the constrained choice, the participant's choice to stay or switch was effective for five consecutive trials.

Materials. Two decks of playing cards were used. The 3-card deck contained an ace and two non-ace cards, and the 10-card deck contained an ace and nine non-ace cards. A chart was provided for participants to record their trial outcomes. Also, there were two versions of the MHP: the original 3-door version and a 10-door version. The 3-door example stated:

> You are a contestant on a game show. An honest game-show host has randomly placed a new car behind one of three identical doors. There is a goat behind each of the other doors. Now you get to select a door.
>
> What is the probability that the car is behind the door that you selected?
>
> After you have selected your door, the host (who knows where the car is) opens up one of the other two doors to show that the car is not behind that door. He will always show you a door that has a goat behind it, and he will never open up your door.
>
> You are now given the choice to stay with your initial door selection or to switch to the other door that you did not select and the host did not open.
>
> Would you like to:
> ________ stay *or* ________ switch
>
> Based on your decision to stay/switch, what is the probability that you will win the car?
>
> Please briefly explain your answers below.

The 10-door version was similar except that the host opened 8 of the 10 doors in order to reveal that the car was not behind those doors.

Procedure. Participants were randomly assigned to one of the eight conditions. Each participant played 30 consecutive trials of either a 3-card or 10-card game. Participants were instructed that the goal of the game was to win the ace on each trial. In the 3-card game, the participant selected a card, and then the experimenter always revealed a non-ace card. The experimenter offered the participant the opportunity to stay with the initial card selection or switch to the other card that was not selected or turned over. Half of the participants were allowed to choose to stay or switch on each trial (free choice) and the other half had a choice that was effective for a block of five trials (constrained choice). After making a stay/switch decision, all cards were revealed. Participants kept a record of the outcome of each card trial on a chart that allowed them to track their wins and losses based on whether they stayed or switched.

The 10-card game followed the same procedure as the 3-card game. In the 10-card game, the participant selected a card, and then the experimenter always revealed *eight* non-ace cards. The participant then decided to stay with the initial card selection or switch to the other card that was not selected or turned over.

Half of the participants were allowed to choose to stay or switch on each trial (free choice) and the other half had a choice that was effective for five trial blocks (constrained choice). All cards were revealed once a stay/switch decision was made.

After completing the card game, participants completed either a 3-door or 10-door MHP. In both MHP versions, participants were given the game show scenario and had to estimate the initial probability that car was behind their door (prior to the host opening a door), make a decision to stay or switch doors, estimate the probability of winning the prize (after the host reveals a door), and explain their reasons behind their choice and probability judgement.

Results and discussion

The results of the card game and MHP were analysed separately.

Card game. Figure 1 shows the mean proportion of switches by trial block (consisting of five trials). Overall, participants learned to switch across

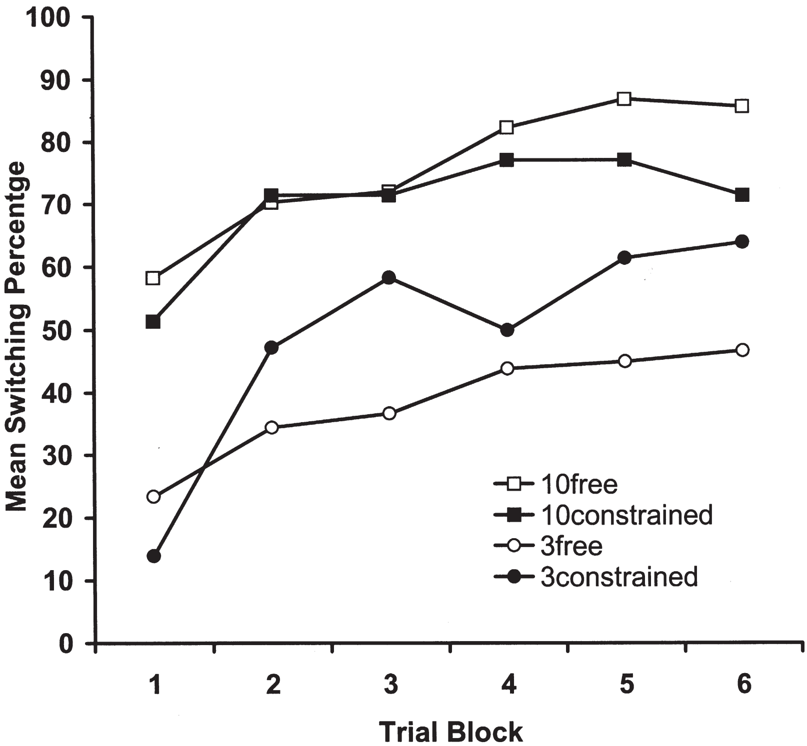

Figure 1. Experiment 1: Mean switching performance across trial blocks based on card game (number of cards and type of choice).

successive blocks. Switching performance in the card game was consistent with the hypothesis that 10-card players would switch more often than 3-card players, and 10-card players began switching at a higher level and continued to switch across trial blocks than did the 3-card players. A mixed factorial ANOVA revealed a main effect for block, $F(5, 690) = 17.46$, $p < .05$, and a main effect for number of cards, $F(1, 138) = 68.51$, $p < .05$. Although the main effect for choice was not significant, the cards by choice interaction was significant, $F(1, 138) = 5.59$, $p < .05$. In order to investigate the nature of the interaction, simple main effect analyses revealed that choice was a factor for the 3-card game, $F(1, 138) = 4.73$, $p < .05$; however, choice did not differentially affect switching performance for the 10-card game. As can be seen in Figure 1, switching was more frequent in the 3-card constrained condition relative to the 3-card free condition, but this pattern is not present for the 10-card conditions. Although the constrained condition resulted in slightly less switching than the free condition in the 10-card game, this difference was not statistically significant. There are two reasons that might explain why the pattern did not emerge in the 10-card condition: (1) switching rates are close to ceiling, so perhaps the null effect in the 10-card condition is due to ceiling effects; (2) perhaps participants learned that switching was better, but decided to make the task more interesting by staying with their initial choice. In fact, six people in the 10-card constrained condition stated that they understood that the probabilities favoured switching but they decided to stay for two or more blocks because it was more “challenging”.

MHP choice behaviour. Figure 2 plots the proportion of switching in MHP as a function of card game played and MHP door problem. The congruency of number of cards seemed to play an important role in transfer from the card game to the MHP for 10-card|10-door participants. Although the 10-card|l0-door condition had greater switching responses than the 3-card|3-door condition, the 10-card|3-door condition also produced more switching in the MHP than the 3-card|3-door condition. Switching in the MHP was not driven solely by the congruency between the card game and MHP, but might also have been affected by the number of cards in the game since the 10-card usually results in more switching than the 3-card game. A 2 × 2 × 2 (cards by doors by choice) log-linear analysis conducted on the number of individuals who decided to stay or switch in the MHP revealed a significant cards by doors interaction, $L^2(l) = 5.35$, $p < .05$. Following the 10-card game, a greater number of participants switched in the 10-door MHP than the 3-door MHP, whereas following the 3-card game there were similar levels of switching for the 10-door and 3-door MHP. None of the other interactions was significant (all ps > .05). Additionally, significant main effects were present for cards and doors, $L^2(1) = 19.48$ and $L^2(1) = 4.64$, $p < .05$, respectively. The main effect of choice was not statistically significant, $p > .05$. The main effect for cards and doors reflects the fact the switching occurs more often for conditions that have greater objective probabilities.

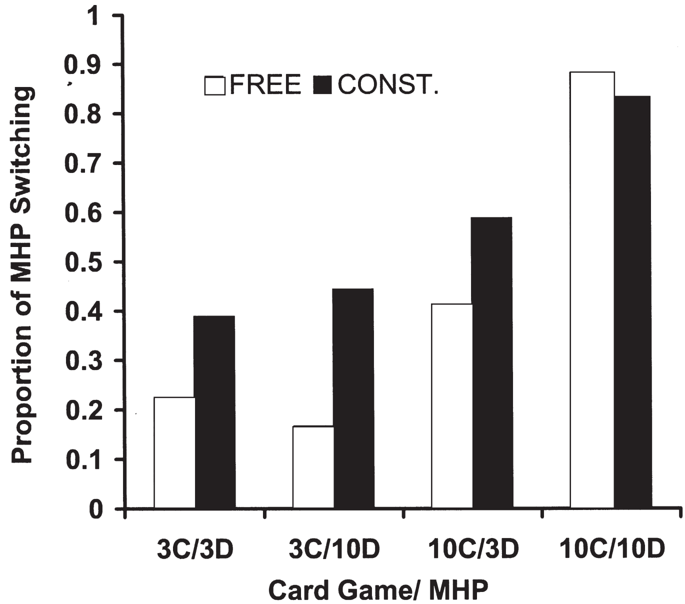

Figure 2. Experiment 1: Proportion of switching in MHP based on card game and HMP version.

In order to assess how experience in the card game might have influenced *switchers'* and *stickers'* stay/switch decision on the MHP, we compared the average number of times that players switched and won in the card game. A 2 (MHP decision: sticker or switcher) × 2 (card game: 3-card or 10-card) ANOVA revealed that there was a main effect of switching and winning where *stickers* (M = 10.81, SD = 7.40) switched and won less often than *switchers* (M = 17.37, SD = 6.30), $F(1, 138) = 9.32$, $p < .05$. As expected, there was a main effect of card game whereby 10-card players won more often than 3-card players, $F(1, 138) = 101.21$, $p < .05$. This reflects the fact the 10-card game results in greater success when players opt to switch. No interaction was present. Thus, switching and winning in the card game presumably led people to switch in the MHP, indicating that at least some participants transferred the switching strategy from the card game to the MHP, particularly for the 10-card game players.

MHP probability judgements. The probability judgment task provides a measure of whether participants learned the probability structure of the MHP. All participants estimated the probability of initially selecting the correct prize as 1/3 in the 3-door MHP and 1/10 in the 10-door MHP. After the host revealed the door(s), the majority of participants judged the probability associated with winning the valuable prize as .50. Analysing the mean probability judgement is uninformative, for the mean does not allow us to consider the proportion of people who change their probability judgement in response to learning in the card game. Accordingly, we examined the probability judgment for *switchers* and *stickers* in terms of the proportion of people who responded with .50, the correct solution; judgements that deviate in the right direction (estimate probabilities towards correct solution, e.g., greater than .50 for *switchers*); and wrong direction (estimate probabilities in opposite direction of correct solution, less than, .50 for *switchers*). As can be seen in Table 1, most people did not gain insight into the actual probabilities of the MHP: Participants overwhelmingly judged the probabilities as .50 regardless of whether they stayed or switched in

TABLE 1

Proportion of stickers and switchers per MHP probability judgement category

Experiment	*Probability judgement*			
Game-MHP	.50	*Correct*	*Right direction*	*Wrong direction*
Experiment 1		*Stickers* ($n = 72$)		
3-card|3-door	.96	.00	.00	.04
10-card|10-door	.60	.20	.00	.20
3-card|10-door	.92	.08	.00	.00
10-card|3-door	.94	.06	.00	.00
		Switchers ($n = 69$)		
3-card|3-door	.81	.18	.00	.00
10-card|10-door	.53	.37	.10	.00
3-card|10-door	.87	.18	.00	.09
10-card|3-door	.88	.12	.00	.00
Experiment 2		*Stickers* ($n = 176$)		
3-card|3-door	.91	.09	.00	.00
10-card|10-door	.86	.11	.00	.03
3-card|10-door	.96	.02	.00	.02
10-card|3-door	.96	.00	.02	.02
		Switchers ($n = 80$)		
3-card|3-door	.81	.19	.00	.00
10-card|10-door	.66	.28	.03	.03
3-card|10-door	.70	.06	.18	.06
10-card|3-door	.72	.11	.17	.00

the MHP. Notably, we see a slight trend where *switchers* deviated more often than *stickers* from the .50, although this difference was not statistically significant. Although few participants generated the correct probability solution, switchers were more likely to do so, particularly in the 10-card|10-door situation. Overall, the similarity between the card game and the MHP did not facilitate the generation of the correct probability response to the MHP for most participants. Note that participants are learning to switch without full understanding of the probabilities involved in the tasks.

We conducted a follow-up experiment to investigate whether the reason that the MHP is particularly difficult is that the conditional probabilities are not explicit. Participants might understand implicitly that the probabilities favour switching, but not explicitly. This result would be consistent with past research showing that people can gain an implicit understanding of the probabilities but not be able to communicate the probabilities verbally (Bechara, Damasio, Tranel, & Damasio, 1997). The follow-up incorporated a hint manipulation whereby participants were informed that they could use the information that they had learned during the card game to solve the MHP. The use of a hint presumably should lead participants to explicitly note the similarities between the two tasks and consequently increase the likelihood of switching in the MHP, as well as the likelihood that participants would recognise the probabilistic similarity between the card game and MHP, thereby leading more people to generate the correct probability estimates. The results were consistent with Experiment 1 and revealed no effect of the hint on choice behaviour and probability judgements. Thus, switching in the MHP is not contingent upon insight into the probabilities of the game and/or the MHP.

The failure of the hint manipulation to increase switching was most likely due to the inability of participants to understand the probabilities associated with the MHP, since the correct solution was never explicitly stated to the participants in our card-game task. Each participant experienced different outcomes in the card game that were based on their stay/switch decisions so that their experience and learning in the card game depended on their choices during the game. Consequently, providing a predetermined outcome to the card game might influence people's propensity to stay or switch in the MHP depending on whether the card game supported staying or switching.

EXPERIMENT 2

In Experiment 2, the outcome of the card game was manipulated so that participants could witness a predetermined outcome that either supported a staying or switching strategy. By presenting the game with predetermined outcomes, we could control how participants interpreted the strategy of the game and whether erroneous positive or negative information influenced switching in the MHP. For instance, always staying in the game and losing the majority of the time should affect the MHP decision if the card game is used to solve the MHP. However, this will depend on the extent to which the game is perceived as rigged (Rachlin, 1989). Even if people believe the probabilities to be equal in the game, they might eventually suspect that the game is rigged when one outcome occurs consistently. However, if the outcome of the game is consistent with expectations, participants might be less likely to notice. The previous experiments revealed that participants tended to rely on learned switching behaviour when deciding to stay or switch in the MHP, since most participants who decided to switch on MHP did not generate the correct probability solution. Thus, the current experiment sought to explain whether trial outcome influenced the MHP stay/switch decision regardless of the underlying probabilities associated with the card game and MHP. We investigated this by manipulating the probabilities independent of the number of cards. Participants were exposed to a card game scenario between a fictitious player and card dealer. In the game, the player always stayed or always switched doors. The outcome of the player's stay/switch decision was revealed and the player either won or lost 90% of the time. Two versions of the card game scenario were developed to support either a staying or a switching strategy: The versions that supported the switching strategy involved a hypothetical player who switched and won or stayed and lost 90% of the time. In the versions that supported the staying strategy, the hypothetical player stayed and won or switched and lost 90% of the time.

We hypothesised that exposure to the fictitious card game should affect switching in the MHP in accordance with the strategy (staying or switching) that was supported by the card game scenario. Although participants were not learning the strategies based on their own performance in the game, we expected them to be influenced by the game because the game would provide a mechanism to learn a particular strategy (stay or switch) without requiring the understanding of the underlying probability structure of the game. We expected that participants would transfer the strategy supported in the game to the MHP, especially for conditions in which there was congruency between the card game and the MHP. Additionally, the conditions that were incongruent should be less influenced by game outcomes because the similarity between the game and the MHP is decreased.

We also hypothesised that MHP probability judgements would not differ across conditions, since participants were passive observers of the game and were not forced to develop their own strategies. If participants do not have the opportunity to learn between the card game and the MHP from their own experience and performance, then they will not be able to generate the correct solution to the MHP and consequently use the .50 probability estimation. Note that only two game scenarios probabilities were accurate: 10-card stay and lose 90% of the time, and 10-card switch and win 90% of the time. Thus, there was the opportunity for participants exposed to these scenarios to generate the correct solution. One might also expect considerably more incorrect solutions in the incongruent conditions since the objective probabilities in the card games do not map onto the objective probabilities of the MHP.

Method

Participants. Introductory psychology students ($N = 259$) at the College of William & Mary participated in the experiment for credit towards partial fulfillment of course requirements.

Design. The experiment consisted of a 2 × 2 × 2 × 2 between factorial design with number of cards in the game (3 or 10), hypothetical player's decision (stay or switch), outcome of the game (win or lose 90% of the time), and MHP (a 3- or 10-door version).

Materials and procedure. Participants were randomly assigned to one of the 16 conditions. Participants viewed a fictitious card game that was placed on 30 3 × 5 index cards. Each index card contained a trial that had occurred between a dealer and a player with the information about the player's decision and outcome. The index cards had either a 3-card or 10-card game scenario similar to the previous experiment except that the fictitious player always switched to the other card or always stayed with the initial card. The outcome of the game was manipulated so that the player either won or lost 90% of the time. After viewing the game, participants completed either a 3-door or 10-door MHP word problem.

Results and discussion

MHP choice behaviour. Figure 3 plots the proportion of switching in the MHP in each of the 16 conditions. The outcome manipulation significantly affected the MHP responses. Overall, participants switched more often in the MHP after being exposed to the index card game in which the switching strategy was supported. In addition, congruent situations produced slightly more switching than the incongruent situations. A 2 (card game: 3-card or 10-card) × 2 (player decision: stay or switch × 2 (game outcome: win or lose) × 2 (MHP: 3-door or 10-door) log-linear analysis conducted on MHP responses revealed significant main effects of player decision and outcome, $L^2(1) = 70.34$ and $L^2(1) = 72.55$, $p < .05$, respectively. The player's decision affected choice behaviour in that participants switched more often when switching was successful for the player and switched less often when switching was not successful for the player. The analysis revealed a three-way interaction for player decision by cards by outcome, $L^2(1) = 81.51$, $p < .05$. Switching behaviour was affected by exposure to either the 3-card or 10-card game, and the impact of being exposed to the game depended on both the player's decision and the outcome of the game. Participants who were exposed to the two conditions that supported a switching strategy (switch and win, stay and lose) switched more often than participants who were

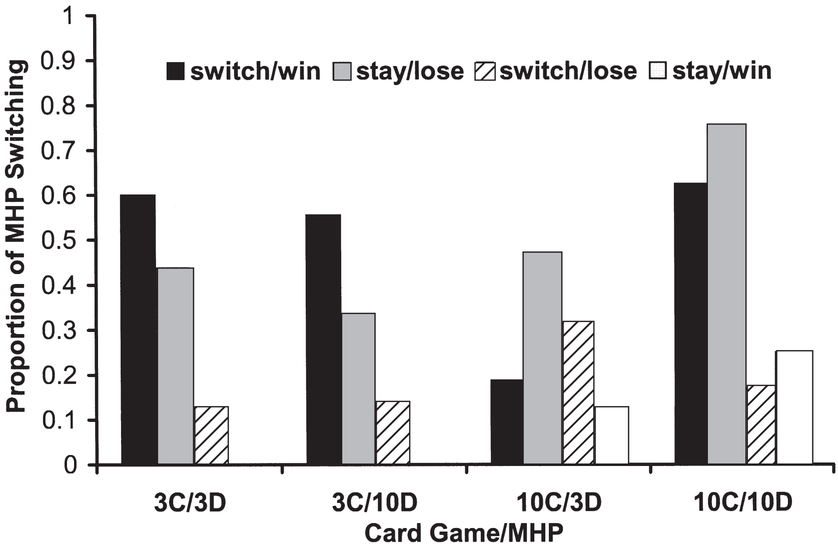

Figure 3. Experiment 2: Proportion of switching in MHP based on simulated game by MHP version.

exposed to the two conditions that did not support a switching strategy (switch and lose, stay and win). However, 3-card and 10-card players seemed to be differentially affected by the player's decision coupled with a specific outcome. As represented in Figure 3, exposure to the 3-card game produced a higher proportion of switching in the MHP when the fictitious player switched and won, whereas a different pattern is observed with 10-card players where the proportion of switching is greatest for the situation where the player stays and loses. Notably, stay and lose situations increase switching for 3-card players, but not to the degree of the switch and win situations. Interestingly, switch and win situations were inconsistent for those who viewed the 10-card game since switching increased in the 10-card|10-door situation but not for 10-card|3-door participants. Additionally, the stay and win condition did not affect switching for 3-card players, a finding consistent with the propensity of people to stay in the MHP. These participants presumably saw this game to be consistent with their own decision to stay in the game. Interestingly, the stay and win situation did not affect 10-card players in the same manner, indicating that perhaps they may have been considering the initial probabilities of winning with the outcome.

There were two second-order interactions that were significant. An interaction was present for player decision by cards, $L^2(1) = 75.30, p < .05$. As represented in Figure 3, participants who viewed the 3-card game seemed to be more influenced by the player's decision to switch, whereas the reverse was true for the participants who viewed the 10-card game—they seemed to be more influenced by the player's decision to stay. A cards by outcome interaction was also present,

$L^2(1) = 47.75$, $p < .05$. Win outcomes played a role in influencing participants who witnessed the 3-card game, whereas lose outcomes seemed to be a factor only for 10-card players.

MHP probability judgements. All participants estimated the probability that the initially selected door contained the correct prize as 1/3 in the 3-door MHP and 1/10 in the 10-door MHP. Consistent with the previous experiments, after the host revealed the door(s), the median probability estimates associated with winning the valuable prize was .50. Perhaps more informative are the proportion of incorrect and correct probability solutions for *switchers* and *stickers.* These data are presented in Table 1 along with the proportion of participants whose probability judgements are in the right and wrong direction. Overall, fewer participants switched in this experiment (approximately 1/3) whereas almost half of the participants switched in the previous experiment. Once again, *switchers* were more likely to deviate from the .50 response, and more *switchers* generated the correct solution, especially in the congruent situations. Consistent with Experiment 1, this difference was not statistically significant. These results are consistent with the hypothesis that people will be less likely to deviate from the equal probability estimation when they have not learned about the under-lying probabilities associated with the game and MHP. Presumably, people view the hypothetical card game and are primed to stay or switch based on the player's outcome without regard to the actual objective probabilities involved with staying and switching. This suggests that learning to switch in the MHP is due merely to superficial similarities between the card game and MHP, without understanding the probabilistic structure of the card game and the MHP.

In Experiments 1 and 2 participants were able to state the correct initial probability of winning prior to the host opening a non-prize door. However, once the host revealed the door(s), participants interpreted the MHP as consisting of a new probabilistic problem space, which seems to comprise the prize over the number of unopened doors. Hence, the .50 response is the most common response for both the 3-door and 10-door MHP problems. Fox and Rottenstreich (in press) demonstrated how probabilities are partition-dependent, indicating that the manner in which the problem space is partitioned will affect the judged probability of an event. The idea that participants partition the probability space can readily be applied to the MHP. Experiments 1 and 2 demonstrated that participants apply a new independent problem space to the MHP once the host has revealed the door(s). Thus, part of the difficulty of solving the MHP might be that people reinterpret the problem space in a new manner once the doors are revealed, which is independent, and not conditional upon, the initial problem space when all doors are closed. Consequently, the problem space that most participants seem to adopt is one that construes the problem as reflecting the number of prizes over the number of unopened doors.

EXPERIMENT 3

Experiment 3 was designed to investigate participants' partitioning of probability structure of the MHP as based on the number of prizes and doors. Varying the number of prizes and doors allowed us to examine how participants partition the MHP problem in situations where the resulting problem space could not be interpreted as .50/.50 (one prize and two unopened doors). Specifically, we created three problems: (1) the original 3-door MHP with one prize; (2) a 4-door MHP with two prizes; and (3) a 5-door with three prizes. In all situations, the host reveals only one door. In the 4-door MHP the initial probability of winning one of the prizes is .50, but once the host reveals one of the doors the probability of switching and winning is .75. In the 5-door MHP the initial probability of winning one of the prizes is .60, but after the host reveals a door the probability of switching and winning is .80.[1] In the previous versions of the MHP with one prize the probabilities of staying and winning and switching and winning were complementary, so they summed to 1.0; however, in the multiple prize situations as described in the 4-door and 5-door problems, the probabilities do not sum to 1.0 since it is possible to win by either staying or switching in any one game. If participants partition the problem space as consisting of the number of prizes over the number of unopened doors, then they should interpret the 4-door problem as .67 (2 prizes/3 unopened doors) and the 5-door as .75 (3 prizes/4 unopened doors).

In addition to the partitioning of probabilities associated with the MHP, we examined whether the perceived value of the prize affected participants' willingness to exchange doors. Participants might endow the value of their door just by the mere fact of selecting the door so that they are unwilling to switch doors without some incentive. The endowment effect occurs when the possession of goods increases the value of that good (Thaler, 1980). Bar-Hillel and Neter (1996) demonstrated that a small monetary incentive is sufficient to entice participants to switch lottery tickets, but only when the lottery tickets are identical. A small incentive might entice participants to switch doors, especially

[1]A formula can be applied to determine the conditional probabilities of the MHP as a function of the number of prizes and doors. If we let x = the number of prizes and n = the number of doors. The initial probability of winning a prize is **x/n** (prizes/doors). The probability of switching and winning is reduced to **n–1/n** (doors–1/doors). The switching and winning probability can be calculated as follows: (a) if the contestant initially selects a door with a prize, then the probability of switching and winning is based on the initial probability of winning (**x/n**) multiplied by (**x–1/x**), the probability of winning the prize after abandoning a door with a prize; (b) if the contestant does not initially select the door with a prize, then the probability of switching and winning is based on the initial probability of selecting a non-winning door (**n–x/n**) multiplied by **(1)** the probability that there is a prize behind one of the remaining doors. The probability of switching and winning is the sum of (a) and (b).

in the MHP situations in which there are multiple prizes. Participants were asked to imagine that they were offered money to exchange doors, and to state the minimum amount of money that they required to exchange their initial door for an unopened door(s).

Method

Participants. A total of 165 undergraduates from the University of Maryland participated in the experiment for credit towards partial fulfillment of course requirements.

Materials and procedure. Participants were assigned to one of three MHP conditions: the original 3-door problem with one prize, the 4-door problem with two prizes, or the 5-door problem with three prizes. All participants completed three installations of the door problem where the type of prize (i.e., television, DVD player, or desk) varied. For the MHP conditions with multiple prizes, participants were told that the prizes were of identical value. For each installation, participants estimated the initial probability that a prize was behind their door (prior to the host opening a door), estimated the probability of winning the prize (after the host reveals a door) for both stay and switch situations, and explained their reasons behind their choice and probability judgement. Additionally, they were offered the opportunity to exchange doors for monetary value of \$0–\$1 (in 10-cent increments) or to decide not to exchange their door.

Results and discussion

Choice behaviour. A log-linear analysis was conducted on switching in the MHP and revealed no significant effect of MHP condition, prize, or the interaction of condition by prize, $p > .05$. The frequency with which participants elected to switch doors across prizes and conditions are presented in Table 2. In all the three conditions of the MHP, at least half of the participants decided to switch for two or more versions of the problem (50% for the 4-door, 52% for the 5-door, and 65% for the 3-door MHP). Of the people who selected to switch, the amount of money they would accept did not differ between MHP conditions. As can be seen in Table 2, the average price was around 50 cents but the standard deviations were also quite large.

Probability judgements. The frequency of participants' probability responses to the 3, 4, and 5-door MHP versions are presented in Table 2. As can be noted, participants did not differ in their assessment of the probabilities associated with the three prize versions of the MHP. A log-linear analysis revealed no effect of type of prize. Consequently, chi-square analyses were conducted for each installation of the MHP since there were some cells with zero responses. Adjusting the alpha level for the separate analyses did not affect the test, as the chi-square analyses revealed a significant effect of probability estimations

TABLE 2

Frequency of stay/switch probability responses after host reveals a door and switching frequency for 3, 4, and 5-door MHP

	MHP		
Prize type	*3-door*	*4-door*	*5-door*
TV problem	(n = 59)	(n = 53)	(n = 53)
Probability, response (stay/switch)			
.50/.50	49	2	1
.67/.67	0	33	0
.75/.75	0	1	33
Correct	0	0	0
Other	1	17	19
Switching frequency	18	19	15
Money to switch: Mean (std.)	$.63(.46)	$.69(.44)	$.40(.47)
DVD player problem	(n = 59)	(n = 53)	(n = 53)
Probability response (stay/switch)			
.50/.50	53	3	3
.67/.67	0	29	0
.75/.75	0	1	33
Correct	1	0	0
Other	5	20	18
Switching frequency	20	12	30
Money to switch: Mean (std.)	$.60(.48)	$.59(.49)	$.49(.49)
Desk problem	(n = 59)	(n = 53)	(n = 53)
Probability response (stay/switch)			
.50/.50	50	5	1
.67/.67	0	29	0
.75/.75	0	1	29
Correct	1	0	0
Other	8	18	23
Switching frequency	28	13	16
Money to switch: Mean (std.)	$.58(.46)	$.64(.45)	$.40(.47)

associated with the MHP door problem for TV, DVD, and Desk problems, χ^2 (8, N = 165) = 217.04, χ^2 (8, N = 165) = 218.07, χ^2 (8, N = 165) = 199.60, all ps < .05, respectively. Of particular interest is the fact that the majority of participants in each version of the MHP provided answers that revealed that they partitioned the problem space as a function of the number of prizes over the number of unopened doors after the host reveals a door that contains no prize. In the 3-door problem, most participants estimated the probability of staying and winning and switching and winning as .50/.50 reflecting the partition of one prize between two doors. Similarly, the participants exposed to the 4-door or 5-door problem were more likely to respond with .67/.67 and .75/.75, respectively, reflecting the partition of 4-door problem as two prizes amongst three doors, and as three prizes among four doors for the 5-door problem. Interestingly, participants' partitioning of the problem space is equal for both stay and switch decisions, despite the fact that the of probabilities are unequal and favour switching. Thus, participants' partitioning of the problem space is consistent with a new interpretation of problem space once the host reveals the door, yet they think that this partition is equally likely irrespective of whether they stay or switch.

GENERAL DISCUSSION

The overall findings indicated that participants were unable to generate the correct probability structure associated with various versions of the MHP. After being exposed to the card game, similarity played a greater role in influencing participants to switch in the MHP, especially when the probabilities overwhelmingly favoured Switching as was the case in the 10-card/10-door condition. Participants learned the switching strategy in the card game and some applied this strategy to the MHP, but they did not seem to be able to correctly discern the probabilities associated with switching either in the game or in the MHP. The decision to stay or switch in the MHP not only involves understanding the objective probabilities, but learning experience also plays an integral role, even when the learning is counter to the actual probabilities involved. As we demonstrated in Experiment 2, participants learn the switching strategy superficially and apply it directly to the MHP. Thus, even when formal rules of probability are not applied, prior experience with the game is sufficient to enhance switching in the MHP, but not in learning the probability structure associated with the game.

Of particular interest is the finding that participants can learn that switching leads to a greater chance of winning, yet not gain insight into why switching is the optimal behaviour. This is interesting because it suggests that there is dissociation between the processes underlying participants' choice behaviour and the processes underlying their probability judgements.

How might we account for the dissociation between choice behaviour and probability judgement? One possibility is to propose a dual-process model whereby choice and judgement are guided by different systems. Sloman (1996; see also Stanovich, 1999) recently proposed a dual-process theory that accounts for our results. One system within this framework is an associative system. The associative system is assumed to be a relatively automatic system requiring little cognitive resource, which is based primarily on associations learned through experience. The second system is a rule-based system. This system is assumed to be a relatively controlled process that is analytic in nature. Accordingly, the hallmark of this system is the application of formal rules of logic or probability theory to solve problems. Although these two processes often give rise to the same solution to any given problem, they sometimes provide conflicting solutions. Thus, dissociations between the two systems can be revealed when the task is one that pits one system against the other, such as is the case with the MHP. Consistent with a dual-process theory, we propose that participants' choice behaviour is guided by their gut-level feelings of certainty that are gained as a result of playing the simulated card game, but that their probability judgements are guided by the application of formal, albeit incorrect, rules. The dissociation arises because the processes that underlie choice and judgement give rise to different answers.

Similar types of dissociations have recently been revealed in judgement and decision-making tasks. For example, Bechara et al. (1997) revealed that normal participants produced anticipatory skin conductance responses prior to selecting a risky deck of cards, and this response preceded their explicit knowledge about the risk associated with the different decks. Berry and Broadbent (1987, 1988) demonstrated that there was a dissociation between participants' performance on a complex knowledge task and their explicit understanding of the task. Evans, Venn, and Feeney (2002) demonstrated how reasoning biases in a hypothesis-testing task can be reduced via instructions that induce participants to think of explicit alternatives rather than relying on implicit assumptions. Additionally, the dissociation between performance and expression of knowledge has been demonstrated in a natural linguistic structure task (Pacton, Perruchet, Fayol, & Cleeremans, 2001). Finally, recent research by Windschitl, Young, and Jensen (2002) suggests that different types of probability responses might tap different systems. Windschitl et al. argue that numeric probability judgements entice participants to employ analytic or rule-based processes, whereas verbal or linguistic likelihood judgements entice participants to rely more on their intuitions. Applied to the Monty Hall problem, this might suggest that having participants provide verbal likelihood estimates might lead to judgements that more accurately reflect the true underlying probabilistic structure of the problem.

Experiment 3 demonstrated that participants partition the probabilities associated with the game as a function of the number of prizes over the number of doors that remain unopened, and they believe that these partitions are equally likely for staying and winning and switching and winning. The partitioning of the probabilities is consistent with an ignorance prior to partition (cf. Fox & Rottenstreich, in press)—participants ignore the initial probabilities associated with the MHP and respond as if revealing a door creates a new problem space that is not conditional on the prior problem space. Unlike Fox and Rottenstreich, the new probability partition does not sum to 1, but the same probability is assigned to both stay and switch situations. For example, participants in the 4-door situation estimated the probability of staying and winning as .67 as well as the probability of switching and winning as .67.

Despite the fact that we found some success in Experiments 1 and 2 in inducing people to adopt the switching strategy in the MHP, some participants are not willing to switch. Why do people have the overwhelming propensity to stay with their initial selection even though the initial selection was chosen at random? One explanation is that it results from the intellectual investment attributed to the first decision (e.g., sunk cost effect, Arkes & Blumer, 1985). As Granberg and Brown put it, "Even when people have no good reason for initial selection, having acted on it, they become psychologically bound or committed to it" (1995, p. 721). People might rely on their intuitions about their decisions, regardless of the initial randomness attributed to the first choice. Additionally, it requires cognitive effort to alter your first decision after having committed to the first choice. People may employ a heuristic decision-making approach in which they devote little time to thinking about alternatives, especially if the outcome likelihood is perceived as equal (cf. Tversky & Kahneman, 1974).

A second reason that people stay with the initial door might have to do with regret. In the MHP, part of the decision process may entail a mental simulation of how it would feel to stay and lose versus switch and lose. Previous research has shown that regret is greater for actions than for inactions. For example, Landman (1988) discovered that people felt greater regret following an action that resulted in an unfavourable outcome than a non-action that resulted in a similar unfavourable outcome. Indeed, there was anecdotal evidence that this was the case. Several participants commented that their choice to stay in the MHP was influenced by their feelings associated with switching and losing. For instance, one participant who stayed in the MHP expressed that "it would stink if I switched and found out that I had the right one in the first place".

Investigations into counterfactual thinking have demonstrated that when two events have equal outcomes, reactions to situations that are closer to the goal elicit stronger feelings than situations perceived to be further away (Landman, 1988; Miller & McFarland, 1987). To justify the outcome of an action, people will attribute greater value to a prize associated with an action versus an inaction that resulted in earning a lower-value prize (Gilovich, Medvec, & Chen 1992). A regret explanation might explain why people have the overwhelming propensity to stay with the initial selection in the MHP, even when they believe the probabilities are equal or even favour switching.

In sum, the present paper has revealed that despite the fact that some participants learned that switching was the optimal behaviour, few were able to discern the underlying probability structure of the task. That some participants learned to switch but failed to learn that the probabilities are greater for switching and winning suggests that participants gained implicit knowledge of the task but did not gain an explicit understanding of why switching was the best strategy. Participants did not learn the objective probabilities associated with the game and/or MHP, and most participants partitioned the probabilities associated with the MHP based on a new problem space that reflects the number of prizes over the number of doors. The lack of generation of the correct probability structure associated with the MHP suggests that this problem's counterintuitive solution is due to the reinterpretation of the problem space once the host has revealed the door(s), and this new problem space does not factor in the prior probabilities associated with the MHP.

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