

**UCLA**

**International Journal of Comparative Psychology**

**Title**

Responses to modified Monty Hall Dilemmas in capuchin monkeys, rhesus macaques, and humans

**Permalink**

<https://escholarship.org/uc/item/1jn0t21r>

**Journal**

International Journal of Comparative Psychology, 31(0)

**ISSN**

0889-3667

**Authors**

Watzek, Julia  
Whitham, Will  
Washburn, David A  
[et al.](#)

**Publication Date**

2018

**License**

[CC BY 4.0](#)

Peer reviewed



## **Responses to Modified Monty Hall Dilemmas in Capuchin Monkeys, Rhesus Macaques, and Humans**

**Julia Watzek<sup>\*1</sup>, Will Whitham<sup>1</sup>, David A. Washburn<sup>1-2</sup>, and Sarah F. Brosnan<sup>1-3</sup>**

**<sup>1</sup>Department of Psychology, Language Research Center, Georgia State University**

**<sup>2</sup>Neuroscience Institute, Georgia State University**

**<sup>3</sup>Department of Philosophy, Center for Behavioral Neuroscience, Georgia State University**

The Monty Hall Dilemma (MHD) is a simple probability puzzle famous for its counterintuitive solution. Participants initially choose among three doors, one of which conceals a prize. A different door is opened and shown not to contain the prize. Participants are then asked whether they would like to stay with their original choice or switch to the other remaining door. Although switching doubles the chances of winning, people overwhelmingly choose to stay with their original choice. To assess how experience and the chance of winning affect decisions in the MHD, we used a comparative approach to test 264 college students, 24 capuchin monkeys, and 7 rhesus macaques on a nonverbal, computerized version of the game. Participants repeatedly experienced the outcome of their choices and we varied the chance of winning by changing the number of doors (3 or 8). All species quickly and consistently switched doors, especially in the eight-door condition. After the computer task, we presented humans with the classic text version of the MHD to test whether they would generalize the successful switch strategy from the computer task. Instead, participants showed their characteristic tendency to stick with their pick, regardless of the number of doors. This disconnect between strategies in the classic version and a repeated nonverbal task with the same underlying probabilities may arise because they evoke different decision-making processes, such as explicit reasoning versus implicit learning.

**Keywords:** Monty Hall dilemma, probabilistic reasoning, heuristics, decision making, capuchin monkeys, rhesus macaques

Suppose you're on a game show, and you're given the choice of three doors. Behind one door is a car, behind the others, goats. You pick a door, say #1, and the host, who knows what's behind the doors, opens another door, say #3, which has a goat. He says to you, "Do you want to pick door #2?" Is it to your advantage to switch your choice of doors?

The Monty Hall Dilemma (MHD) is a brain teaser, presented here in its most (in)famous form as it was 28 years ago in *Parade Magazine* (vos Savant, 1990). For most people, it does not initially pose a dilemma at all. Across 13 studies that used standard versions of the MHD, participants overwhelmingly ( $M = 85.5\%$ ,  $SD = 4.5$ ) chose not to switch doors (Burns & Wieth, 2004). However, people who switch doors actually double their chances of winning the car (see below). The mystifying nature of the problem is the characteristic inability for people to set aside their intuition and accept the demonstrably correct solution. This tendency occurs across cultures (Granberg, 1999) and appears to be largely immune to expertise (vos Savant, 1997). Indeed, much of the legend of the MHD emerges from this inability to discard a sticky initial intuition – most famously with 92% of angry letter writers telling Marilyn vos Savant that her solution to switch, as described in the *Parade Magazine* edition of the problem, was flawed (vos Savant, 1997).

Our intuition produces fast and fluent responses that “feel” right (Thompson, Evans, & Campbell, 2013), and our difficulty in overcoming our intuition is well documented. This can lead to poor decision making, including the aforementioned tendency to stick with a choice despite evidence to the contrary. In this study, we take a comparative approach to better understand the evolution of the cognitive processes that lead to our stubborn decisions to stick with our initial choice. We tested capuchin monkeys, rhesus macaques, and humans to assess the extent to which other animals show this same response bias in the MHD. This approach can tell us whether the underlying mechanisms are likely to be unique to humans or are shared with other species, which can help us understand how these biases evolved and, potentially, give us insight into how to overcome them.

Several cognitive biases may influence responses to the MHD. One is the equiprobability heuristic, or uniformity belief (Falk, 1992; Tubau & Alonso, 2003), which would lead participants to think that the two remaining doors (and, therefore, both staying and switching) each have a 50% chance of being correct. Indeed, when, in addition to switching and staying, participants were given the option to indicate whether they thought that the chances that the reward was behind the two remaining doors were equal, 86% indicated this belief (De Neys & Verschueren, 2006). However, this would only be true if the car were randomly placed behind the two remaining doors. Instead, it is placed randomly behind the initial three doors. Consider the three possible scenarios that the car is behind Doors 1, 2, and 3, respectively. If the car is behind Door 1, the contestant wins by sticking to it. If the car is behind Door 2, then the host has to open Door 3 because he cannot open the contestant’s chosen door, which has the other goat. Thus, switching to Door 2 would guarantee the car. Similarly, if the car is behind Door 3, then the host has to open Door 2, and switching to Door 3 again wins the car. Thus, sticking with the initial choice wins in one out of the three scenarios (1/3) and switching wins in two out of the three scenarios (2/3).

The equiprobability heuristic alone, however, would only result in indifference between staying and switching. Assuming that switching cannot improve one’s odds in any way, people may stay with their gut feeling due to several other cognitive biases. First, the endowment effect (Thaler, 1980) may lead people to value their chosen door more than the remaining unchosen door. Second, loss aversion (or emotional amplification – when the psychological magnitude of a loss is greater than that of a win) and errors of commission (when decisions to act are perceived as bearing greater consequences than decisions not to act) may lead people to anticipate that they would feel worse after switching and losing than after staying and losing. Indeed, participants who switched and lost rationalized their loss by later valuing their consolation prize more highly than did participants who did not switch and received an identical consolation prize (Gilovich, Medvec, & Chen, 1995). Further, when participants did not make the initial choice themselves (and, therefore, had less opportunity for regret), they were more likely to correctly switch (Saenen, Heyvaert, Grosemans, Van Dooren, & Onghena, 2014; Stibel, Dror, & Ben-Zeev, 2009).

Although these “stick-with-your-gut” heuristics and the equiprobability heuristic combined can lead to our overwhelming tendency to stay with our first choice, developmental evidence suggests that they may rely on different processes. De Neys (2007) found that 12-year-olds were just as likely to indicate that staying was the strategy most likely to win as they were to indicate that the chances of winning were equal. On the other hand, 17-year-olds overwhelmingly indicated that the chances were equal and few of them thought that staying was better. Thus, our tendency to stick may develop early on, perhaps rooted in emotional responses, whereas the equiprobability heuristic, which is computationally somewhat more complex, may come online later. Interestingly, in this case, a developmental increase in cognitive resources and formal statistics education may not necessarily lead to more analytical reasoning but instead to use of a different heuristic. Overriding the

intuition that arises from these different heuristics in order to correctly switch doors seems to require additional cognitive resources. Indeed, the minority of adult participants who switched doors in the MHD had significantly higher working memory capacity, and switch responses were depressed further under concurrent cognitive load (De Neys, d’Ydewalle, Schaeken, & Vos, 2002; De Neys & Verschueren, 2006; however, see Stibel et al., 2009, for evidence that increased load may facilitate switch responses).

## **Comparative Approaches to the Monty Hall Dilemma**

Only a few studies have explored the MHD in species other than humans. Assessing the extent to which other animals do or do not share our response bias provides more insight into its fundamental cognitive features, and it is important to understand the degree to which they are shared between humans and other species. In particular, other species’ responses to the MHD are likely to be based more in associative mechanisms than is true in humans, but this is difficult to determine because current studies of the MHD in humans are embedded in language.

Aside from making it difficult to compare our responses to those of other species, the use of linguistic framing in human studies also makes it difficult to know what other basic cognitive features characterize the MHD response. We know that linguistic framing changes humans’ responses. For example, different cover stories or even subtle changes in how the problem is worded can affect MHD responses in humans (Krauss & Wang, 2003). By using a nonverbal task and by comparing human performance to that of species without human language, we can eliminate the linguistic component of the problem and therefore tease apart its influence on strategies in the MHD.

Herbranson and Schroeder (2010) offered six pigeons (*Columba livia*) a computerized version of the MHD, using an operant chamber with three response keys (corresponding to the three doors of the MHD). Selection of one response key was taken as the initial choice. Two of the three keys were then illuminated (the pigeon’s initial selection and one other key) and the third key was darkened and no longer permitted as a response option (corresponding to the host opening a losing door). Pigeons then made a second selection – either choosing their initial choice once more (a stay response) or choosing the initially unselected key (a switch response). In this repeated version of the MHD, the pigeons switched on approximately 36% of trials on their first day of testing, which increased to approximately 96% of trials on Day 30. However, humans tested on the same paradigm also did not show their characteristic stay response. Instead, they were initially indifferent, and increased to switching approximately 70% of the time. Unfortunately, we do not know how pigeon and human performances compared across similar numbers of trials, but neither species showed a consistent bias to stay with their initial choice. In a different computerized MHD, humans, pigeons, and, to some extent, preschool children all showed the same general pattern of switching approximately 70%, although there were substantial individual differences (Mazur & Kahlbaugh, 2012).

Zentall, Case, and Collins (2015) offered a further exploration of pigeons’ responses to the MHD. When the initial choice was made for them (Forced-Choice Group; mirroring the design used by Stibel et al., 2009), pigeons maintained chance levels of switching throughout the experiments. However, pigeons who made the initial choice themselves (Free-Choice Group; as in most versions of the MHD) quickly adopted high levels of switching. That is, contrary to humans, they were more likely to switch when they were free to pick the initial door. However, further analyses revealed that key preferences (side biases) may account for this pattern. Specifically, pigeons in the Free-Choice Group could pick their preferred key on the initial choice, and

learn to switch on the second choice. Pigeons in the Forced-Choice Group, on the other hand, used their only (“second”) choice to pick their preferred key, thus enabling stimulus preferences to preclude learning of the task contingencies (and the optimal response to them).

Klein, Evans, Schultz, and Beran (2013) applied a new computerized version of the MHD to 7 rhesus macaques (*Macaca mulatta*) and 15 human participants. Both species were presented with three black squares (corresponding to the three doors) on a computer screen. Using a joystick-controlled cursor to select one of the black squares caused one of the unselected black squares to move upward, revealing a red square (corresponding to the host revealing a losing door). Like the pigeons, participants then made a second choice between the two remaining boxes to stay or switch. Neither species showed a strong initial propensity to stay with their initial choice, as in classic versions of the MHD. Both species demonstrated robust individual differences, with a subset of individuals of each species (five humans, three macaques) adopting the optimal, switch-heavy strategy. The source of these individual differences among the switch-biased and stay-biased macaques is left unknown, however, and was not systematically related to age, testing experience, or testing “productivity” (completed trials per day).

This diversity of results from comparative studies of the MHD is quite different from classic text-based studies with humans. In these nonverbal, computerized MHD tasks, the predisposition to stay with an initial choice is weaker or not present in the first place. These designs offered animals, including humans, much more experience than the classic one-shot MHD does (hundreds or thousands of trials in each reviewed study). In such a context, the contributions of associative principles is more obvious, as when pigeons’ switch responses are guided less by endowment effects and more by rote stimulus preferences (Zentall et al., 2015). Further exploration of the comparative psychology of the MHD promises to contribute still more to our understanding of the potential differences between implicit and explicit learning of the task contingencies.

## **The Present Study**

The goal of the present study was to explore how various features of the task could influence decisions in the MHD in three primate species. We first explored the effect of experience with an iterated computerized version of the MHD on switch rates. We predicted that on early trials, human participants would show the same switch aversion that is so characteristic of the MHD. We further predicted the same pattern from both species of monkeys, given that rhesus macaques have been known to persevere in their choices in other probabilistic two-choice paradigms (Lee, Conroy, McGreevy, & Barraclough, 2004). However, on later trials, we expected that repeated exposures to the outcomes of their decisions would elicit greater frequency of switching behaviors in the task in all three species (as in Granberg & Brown, 1995).

Additionally, previous work indicates that varying the number of doors can improve intuitions about the MHD (e.g., Franco-Watkins, Derks, & Dougherty, 2003; Granberg & Dorr, 1998; Nickerson, 2004; Page, 1998; Saenen et al., 2014; Stibel et al., 2009). Specifically, higher door numbers have helped to facilitate switch responses, but the effect is not always present from trial one. In the current study, we varied the number of doors that were available before the initial choice. In one condition, participants chose among three doors, as in most formulations of the MHD. In a second condition, participants chose among eight doors. We hypothesized that switching would be adopted more quickly in the eight-door than in the three-door version of the task.

For the humans, we also collected survey-based responses to the classic one-shot version of the MHD with either three or eight doors among which to choose. This measure was completed after the computerized MHD or after an unrelated computer task from experimental psychology (control condition). In doing so, this measure tested the generalizability of learning the switch rule for the MHD. Previous evidence for whether such generalization occurs has been inconsistent and was done in a task without an experimental control group (Franco-Watkins et al., 2003). We hypothesized that experience with the iterated computer version of the MHD would encourage switch responses in the classic version of the task compared to experience in a control computer task. Furthermore, we hypothesized that participants with experience in the eight-door condition of the computerized MHD task would switch more frequently in the one-shot task than individuals who completed the three-door computer task because they should be more likely to have learned to switch in the eight-door than in the three-door computer task. Finally, we predicted that, as in the computer task, participants would be more likely to switch in the eight-door than in the three-door one-shot MHD.

## Method

### Subjects

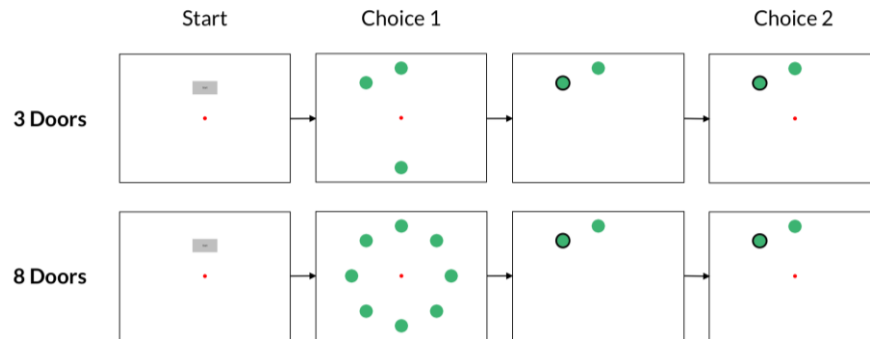
We recruited 264 undergraduates from Georgia State University's online participant pool (69.3% female, 25.8% male, 1.2% other, 3.8% declined to answer;  $M_{age} = 21.0$  years,  $SD_{age} = 4.0$  years [specific ages were only obtained for  $n = 100$  participants, but all participants had to be between 18 and 40 years to be eligible to sign up for the study]; 14.4% Hispanic, 4.9% declined to indicate their ethnicity; 31.4% Black/African American, 26.9% Caucasian/White, 22.7% Asian, 1.5% American Indian/Alaskan Native, 0.8% Hawaiian/Pacific Islander, 6.1% more than one race, 10.6% declined to indicate their race). Students received course credit for their participation in the study.

We also tested 24 capuchin monkeys (16 female, 8 male,  $M_{age} = 16.25$  years,  $SD_{age} = 8.03$  years, age range: 6 to ca. 43 years) and 7 rhesus macaques (all males,  $M_{age} = 22.00$  years,  $SD_{age} = 6.95$  years, age range: 15-35 years) housed at the Language Research Center of Georgia State University. Capuchin monkeys were socially housed in mixed-sex groups in large indoor/outdoor enclosures. Capuchins separated voluntarily into attached testing boxes for cognitive and behavioral studies. Rhesus macaques were individually housed in enclosures that doubled as testing enclosures with continuous auditory and visual access to other macaques and, when possible, had regular social periods with compatible partners. Monkeys of both species could choose not to participate at any time, had ad libitum access to water, including during testing, and were never food deprived for the purposes of this study. All testing food was given in addition to their daily diet of vegetables, fruit, and primate chow.

### Materials

**Computerized Monty Hall Dilemma.** We tested participants on a simple, nonverbal, repeated version of the MHD (Figure 1). They began a trial by moving their cursor into contact with the start box. In the three-door condition, the first response screen then showed three green circles (Figure 1, top) in positions that were determined randomly among eight possible positions at the beginning of each trial. In the eight-door condition, the screen showed green circles in all eight positions (Figure 1, bottom). One of the green circles ("doors") was randomly assigned to be correct ("have the car behind it"). When participants chose one of the circles, it was highlighted with a dark border, and all but the chosen circle and one other circle disappeared. Structurally, this step corresponds to Monty Hall opening doors with goats behind them; that is, only incorrect circles could disappear and the chosen circle always remained on the screen ("unopened"). The cursor was reset to the center of the screen, following which participants then made a second choice between the two remaining circles, either "staying" with their first choice (selecting the circle with the border again) or "switching" to the other circle. If the incorrect circle was selected, participants heard a buzzer sound; if the correct circle was selected, participants heard a whoop sound and both monkey species additionally received a 45-mg grain-based, banana-flavored food pellet (Bio-Serv, Flemington, NJ). Trials were followed by an intertrial interval of 1 s for humans and 5 s for both monkey species.





**Figure 1. Trial progression in the three-door (top) and eight-door (bottom) condition of the computerized Monty Hall Dilemma.** The red dot was the on-screen cursor, which the participants controlled via joystick (both monkeys species) or keyboard (humans). After selecting the start box, participants chose one of either three or eight “doors.” All doors then disappeared except for their chosen door (highlighted with a border) and one other. The cursor reset to the screen center, and participants then made another choice between these two remaining doors. (Border width is not to scale. To aid illustration, it is wider here than it was in the actual test.)

## Procedure

For the two monkey species, we used a within-subjects design (computer task: three vs. eight doors). Monkeys from both species were tested individually on a computer testing system, in which they made their choices by moving the on-screen cursor with a joystick (described in detail in Evans, Beran, Chan, Klein, & Menzel, 2008). They could complete as many trials as they wanted per day and were tested repeatedly on different days until they completed two blocks of 500 trials, one in the three-door condition and one in the eight-door condition. Sixteen monkeys (13 capuchins, 3 rhesus macaques) began with three doors, and 15 monkeys (11 capuchins, 4 rhesus macaques) began with eight doors. Monkeys from both species completed testing in  $Mdn = 2$  sessions ( $IQR: 2-4$ , range: 1-22 sessions, but only two capuchin monkeys took more than eight sessions).

For the humans, we used a between-subjects design. First, we assessed participants’ choices in the computerized MHD (three vs. eight doors). Second, we assessed their choices in the one-shot MHD (three vs. eight doors) following the computer task (three doors vs. eight doors vs. control). Participants were tested individually in a computer laboratory, making their choices by moving the on-screen cursor with the arrow keys on a standard keyboard. They received no verbal instructions except for how to move the cursor and which sounds followed correct and incorrect choices. Participants either completed the computerized MHD ( $n = 100$ ) or one of several unrelated computer tasks from experimental psychology (control condition,  $n = 164$ ). For the computerized MHD, participants completed a single block of either the three- or eight-door condition for up to 500 trials or 45 min (whichever occurred first). Participants completed a  $Mdn = 493.5$  trials and all participants completed at least  $Min = 248$  trials.

After the computer task, we presented humans with either the three-door or eight-door one-shot MHD on a sheet of paper (adopted from Krauss & Wang, 2003, to eliminate as much ambiguity around the problem as possible; see *Appendix*). Also included on the sheet was an open-ended question about the participant’s reasoning about their responses (“Please tell us in writing what went on in your head when you made your decision. You may use sketches, etc., to explain your answer.”), whether they were already familiar with the task, and whether they already knew the correct answer. Humans were tested in a single session that lasted no longer than 60 min.

**Data analysis.** We used linear mixed-effects models to analyze the proportion of switch decisions in the computer task. To determine whether species differed in their switch rates, we included species (human, capuchin monkey, or rhesus macaque), condition (three or eight doors), and their interaction as fixed effects. To further determine whether the order in which the two monkey species experienced the conditions affected switch rates, we refitted the monkey data to a second model with species (capuchin monkey or rhesus macaque), condition (three or eight doors), order (three to eight or eight to three), and their interactions as fixed effects. We included participant identity as a random effect in both models to account for nonindependence of data points. To analyze whether humans decided to stay or switch in the one-shot task, we used a logistic regression model. We included condition (three or eight doors) and previous computer task to doors (three-door MHD, eight-door MHD, or control) as predictors. We used R 3.4.3 (R Core Team, 2017) and the *lme4* (Bates, Mächler, Bolker, & Walker, 2015) package to fit the models, likelihood ratio tests using single-term

deletions to assess the test predictors' importance, and the *lsmeans* package (Lenth, 2016) to compute pairwise contrasts with the Tukey correction for multiple comparisons.

Further, we assessed how humans explained their decision in the one-shot task by scoring each participant's free-form response with respect to three categories: 50-50, intuition, and loss aversion. Responses were coded as *50-50* if participants referred to the chance of winning the car being equal between staying and switching (by using keywords such as "fifty fifty", "50/50", "50%", "1/2", or "coin flip"). Responses were coded as *intuition* if they indicated trust in their first choice (by using keywords such as "intuition", "go with gut feeling", "trust my instinct", and "not second guessing"). Responses were coded as *loss aversion* if participants indicated feeling worse after switching and getting it wrong than after staying and getting it wrong. Categories were not mutually exclusive; that is, responses could be classified into zero, one, two, or all categories. A second coder (who was blind to the study design and hypotheses) scored 100 of the responses and interrater reliability was excellent (Cohen's  $\kappa$  for 50-50: 1, intuition: .94, loss aversion: .88).

## Results

### Computer Task

We found significant main effects of species,  $\chi^2(2) = 35.45$ ,  $p < 0.001$ , and condition,  $\chi^2(1) = 19.49$ ,  $p < 0.001$ , and a nonsignificant trend toward a Species  $\times$  Condition interaction,  $\chi^2(2) = 4.62$ ,  $p = 0.099$ , on the proportion of switch responses in the computerized MHD (Figure 2). Participants switched less in the three-door condition than in the eight-door condition,  $t(75.47) = -3.01$ ,  $p = 0.004$ , and humans switched more than capuchin monkeys,  $t(106.92) = -6.27$ ,  $p < 0.001$ , and showed a nonsignificant trend toward switching more than rhesus macaques,  $t(92.46) = -2.17$ ,  $p = 0.082$ .

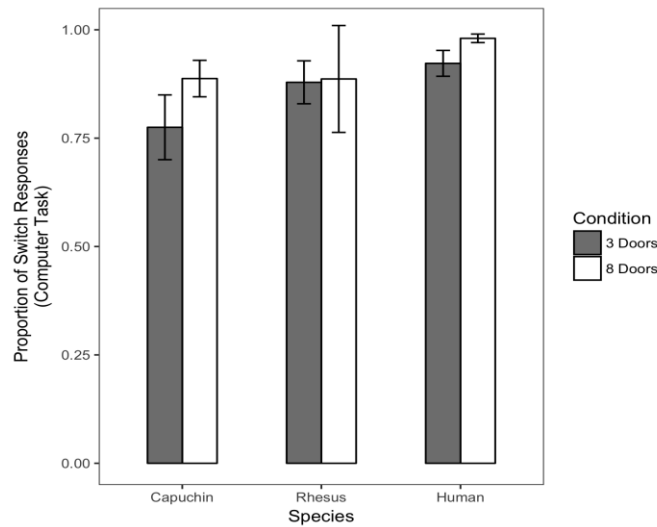
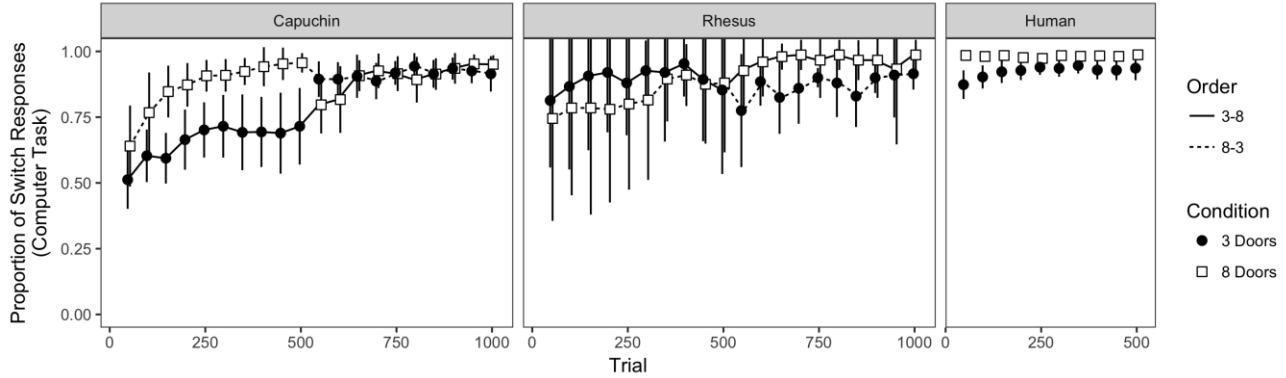


Figure 2. Mean proportion of computer trials in which the switch response was used by condition and species. Error bars represent 95% confidence intervals.

Looking more closely at the two monkey species, we found a significant Species  $\times$  Condition  $\times$  Order interaction effect,  $\chi^2(1) = 4.24$ ,  $p = 0.040$ , on how often the switch response was used (Figure 3). That is, capuchin monkeys and rhesus macaques showed different two-way interactions between condition and order.



Rhesus macaques' proportion of switch responses did not vary significantly with either condition or order (Figure 3, middle panel,  $p > 0.05$ ). For capuchin monkeys, however, switch responses were significantly lower in the three-door condition when it was presented before the eight-door condition than when it was presented after the eight-door condition, (Figure 3, left panel,  $t(40.04) = -5.70$ ,  $p < 0.001$ ). Indeed, capuchin monkeys switched less in the three-door than the eight-door condition only when it was presented first,  $t(27) = -8.85$ ,  $p < 0.001$ , but not when it was presented second,  $t(27) = 1.39$ ,  $p = 0.176$ .

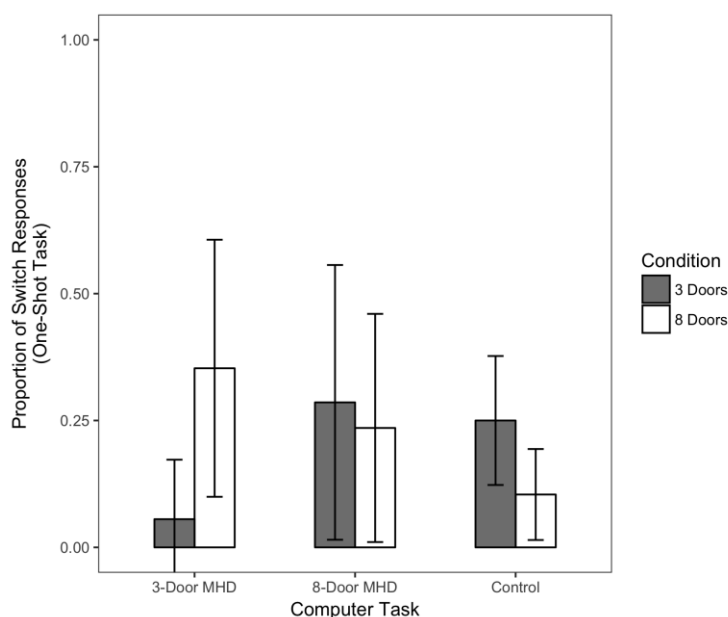


**Figure 3. Mean proportion of computer trials in which the switch response was used by species, condition, and trial (shown as a mean over groups of 50 trials for visualization).** Capuchin monkeys and rhesus macaques completed 500 trials of each condition (within-subjects); humans completed 500 trials of either the three- or eight-door condition (between-subjects). Error bars represent 95% confidence intervals.

## One-shot Task

We excluded the one-shot data of one human participant who did not indicate whether she wanted to stay or switch and the data of 101 of the 264 human participants (38.5%) who were already familiar with the MHD, including 27 participants who further indicated that they knew what the correct answer should be. Indeed, 19 of those 27 participants (70.4%), as well as 24 of the 74 (32.4%) who were just familiar with the game (but indicated that they did not know the correct answer), chose to switch doors. By comparison, only 32 of the remaining 162 participants (19.8%), who were not already familiar with the game, chose to switch.

We found a significant interaction effect between condition and preceding computer task,  $\chi^2(2) = 8.66$ ,  $p = 0.013$ , on the number of participants who chose to switch doors in the one-shot task (Figure 4). Specifically, when the one-shot task followed the three-door computer task, switch rates tended to be lower in the three-door than in the eight-door condition,  $Z = -1.94$ ,  $p = 0.052$ . In contrast, when the one-shot task followed a non-MHD computer task, switch rates tended to be higher in the three-door than in the eight-door condition,  $Z = 1.82$ ,  $p = 0.069$ . However, these were both nonsignificant trends after correcting for multiple comparisons.



*Figure 4. Mean proportion of humans who switched doors in the one-shot task by condition and preceding computer task. Error bars represent 95% confidence intervals. MHD = Monty Hall Dilemma.*

When participants reasoned about their decisions, 28.5% of those who stayed and 28.1% of those who switched indicated that the chance of winning was equal between staying and switching; 38.5% of those who stayed and 9.4% of those who switched wrote that they relied on their intuition; and, 4.6% of those who stayed explicitly wrote that they anticipated feeling worse after switching and getting it wrong than after staying and getting it wrong.

## Discussion

Capuchin monkeys, rhesus macaques, and humans all successfully learned to switch at high rates in our computerized Monty Hall Dilemma (MHD). Against both our predictions and previous experimental evidence, none of the species showed an initial aversion to switch. Even the lowest initial switch rate was around 50% (i.e., indifference), which was for capuchins who were tested in the three-door condition first. However, those capuchins who experienced the eight-door condition first generalized their learned switch strategy immediately to the three-door condition. As expected, increasing the number of doors from three to eight – and thus increasing the chance of winning by switching from  $2/3$  to  $7/8$  – led to a higher proportion of switch responses. Humans used the switch response at slightly higher rates and did so earlier than the two monkey species (although the differences were small), suggesting that they had no trouble learning the underlying probabilities and reward rates through repeated exposure and feedback.

Unlike in previous studies using an iterated MHD computer task (Herbranson & Schroeder, 2010; Klein et al., 2013, Mazur & Kahlbaugh, 2012), rhesus macaques and humans in our study consistently showed near-optimal responding. Five of the seven rhesus macaques had participated in Klein and colleagues' (2013)

task and the human participants were recruited at the same university (i.e., the same population), but here they switched much more consistently than in the previous study. One possibility is that our task made it easier for participants to learn the switch strategy. We did not provide humans with any verbal instructions about the structure of each trial, forcing them to figure out the task parameters on their own – as other species always must do. Others have used more traditional approaches, providing more information to the human participants. Klein and colleagues (2013) told their participants that the computer would provide more information about where the prize was not located, and Mazur and Kahlbaugh (2012) explicitly told participants that “using the best possible strategy, a player can win about 67% of the trials” (p. 413). It is interesting that even a few sentences may lead people to show much more variable strategies, perhaps by affecting people’s expectations and intuitions about the problem. It is possible that the humans relied too much on the (additional) verbal information to conceptualize the problem and therefore failed to follow the cues they received from the task.

One aspect of the problem is to understand that the second decision is related to the first and not an unrelated decision in a new trial. The instructions may have made this clear to the humans from the start, whereas we do not know whether the pigeons and macaques understood the task this way. In our study, we all but eliminated the verbal instructions for the humans, so that all species had to learn only by doing. We employed fewer moving parts (no animation of a door moving off-screen) and differentiated the chosen door from the unchosen one by drawing a border around it. This may have helped both the two monkey species and the humans learn to switch doors by taxing their working memory less, which has previously been shown to encourage switch responses in the MHD (De Neys et al., 2002; De Neys & Verschueren, 2006). In the absence of verbal instructions, highlighting the first choice may have made it clearer to all species that it was related to the second choice or may have made them consider its role in more detail. Finally, for the five rhesus macaques who previously participated in Klein and colleagues’ (2013) study, the task may have simply been easier because they had experience with a similar one. It is possible that the increased experience led to the high switch rates they showed in our task, even when they completed the three-door version first (which did impede the capuchin monkeys). However, the macaques completed Klein and colleagues’ (2013) task at least six years ago and the performance of these five rhesus macaques seemed similar to that of the other two macaques. Thus, experience with the previous task may have only had a small, if any, effect on their behavior in this study.

The results from the computer task stand in stark contrast to humans’ responses in the classic one-shot version of the MHD. Only about one in five participants chose to switch doors in the one-shot task, regardless of which computer task they had completed before and regardless of the number of doors (and therefore profitability of switching). This switch percentage is highly similar to switch rates that have been previously reported, across both studies that included a repeated MHD-like task first (e.g., Franco-Watkins et al., 2003) and studies that did not (e.g., Krauss & Wang, 2003). When participants repeatedly experienced the outcomes of their choices, they quickly learned that switching consistently led to the highest chance of winning. However, they did not generalize this strategy to the classic text version of the MHD.

This disconnect between the humans’ characteristic tendency to stay in the classic one-shot version despite near-optimal switch responses in our iterated computerized MHD may arise from differences between decision making based on explicit reasoning in the one-shot task and that based on implicit learning in the computer task. In other probabilistic tasks, such as statistical learning or weather-prediction experiments, humans have been shown to learn and respond based on artificial grammars and the predictive value of arbitrary cues without being able to explicitly describe that or what they had learned (Gluck, Shohamy, & Myers, 2002; Zhao & Yu, 2016). Similarly, Heilbronner and Hayden (2016) reported that rhesus macaques, like humans, showed a so-called description-experience gap in risky choice tasks, changing their risk preferences depending

on whether the payoff probabilities were described (for the macaques: visually cued) or learned through experience. A similar gap may be responsible for the change in strategies in the “described” one-shot MHD and the “experienced” computer MHD.

Indeed, verbal information before the computer task (as in Klein et al., 2013, and Mazur & Kahlbaugh, 2012; see above) led to more stay responses than we found in the present study, suggesting that using verbal information may trigger explicit reasoning processes and heuristics that interfere with our implicit ability to track the better-paying strategy. From this perspective, it is not surprising that the purely verbal one-shot MHD would invoke explicit processes that overwhelmingly lead us to stay with our initial choice.

Interestingly, we found that among those that switched and those that stayed with their first pick, a similar proportion expressed the belief that staying and switching had the same 50% chance of winning the car. However, those that switched were much less likely to say that they relied on their gut feeling or intuition when they explained their decision than did those who stayed. This finding suggests that people who find the correct solution do not necessarily understand the actual probabilities better but may trust their *first* choice less than those who stay. Perhaps they feel less psychological ownership over their choice (i.e., the endowment effect) or, relatedly, do not anticipate feeling worse if they switched away from it and lost than if they stayed with it and lost (i.e., loss aversion and errors of commission). In this study, we coded participants’ explicit open-ended responses, whereas previous studies had participants choose among “stay”, “switch”, and “chances are equal” (e.g., De Neys, 2007). Our results therefore provide convergent evidence that the equiprobability heuristic may rely on different cognitive processes than those heuristics that favor stay responses. Future research that manipulates these effects experimentally is needed to better understand the underlying psychology of switch and stay decisions in the MHD. Additionally, as a reviewer pointed out, it would be insightful to further assess humans’ explicit thought processes (e.g., whether they recognize the connection between the computer and classic MHD versions, whether they think of the second choice as switching or as making a new choice, and whether they could describe their strategy in the computerized MHD).

## Conclusion

In this study, we found strong similarities in the responses of capuchin monkeys, rhesus macaques, and humans in a computerized version of the MHD. Clearly, simply porting the probability structure of the MHD to a new task environment is not enough to elicit the characteristic stay response that makes the MHD so counterintuitive. Although we have argued for a comparative approach to understanding the psychological underpinnings of the MHD, future research will need to more fully demonstrate that the computerized MHD is truly psychologically similar to the classic MHD. Specifically, it will be important to determine which features of the one-shot task can be implemented into a computer task (or other nonverbal task) in which humans do show their characteristic switch aversion. This will allow us to unpack the MHD phenomenon and pinpoint the specific role of different mechanisms (e.g., those underlying different heuristics or implicit vs. explicit decision-making processes). Presenting the same task to other species, as we have done here, will then help us further understand the psychological mechanisms underlying this notorious brain teaser and to what extent they are shared with other species.

## Acknowledgments

We thank Praful Gade for help with inter-rater reliability coding and the veterinary and animal care staff at the Language Research Center for maintaining the health and well-being of the monkeys. The data that support the findings of this study are publicly available at the Harvard Dataverse (Watzek, Whitham, Washburn, & Brosnan, 2018): <https://doi.org/10.7910/DVN/KAGLJU>

## References

- Bates, D., Mächler M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, 67, 1–48. doi:10.18637/jss.v067.i01
- Burns, B. D., & Wieth, M. (2004). The collider principle in causal reasoning: Why the Monty Hall dilemma is so hard. *Journal of Experimental Psychology: General*, 133, 434–449. doi:10.1037/0096-3445.133.3.434
- De Neys, W. (2007). Developmental trends in decision making: The case of the Monty Hall Dilemma. In J. A. Elsworth (Ed.), *Psychology of Decision Making in Education, Behavior, and Risk Situations* (pp. 271–281). Hauppauge, NY: Nova Science Publishers.
- De Neys, W., d’Ydewalle, G., Schaeken, W., & Vos, G. (2002). A Dutch, computerized, and group administrable adaptation of the operation span test. *Psychologica Belgica*, 42, 177–190.
- De Neys, W., & Verschueren, N. (2006). Working memory capacity and a notorious brain teaser: The case of the Monty Hall Dilemma. *Experimental Psychology*, 53, 123–131. doi:10.1027/1618-3169.53.1.123
- Evans, T. A., Beran, M. J., Chan, B., Klein, E. D., & Menzel, C. R. (2008). An efficient computerized testing method for the capuchin monkey (*Cebus apella*): Adaptation of the LRC-CTS to a socially housed nonhuman primate species. *Behavior Research Methods*, 40, 590–596. doi:10.3758/BRM.40.2.590
- Falk, R. (1992). A closer look at the probabilities of the notorious three prisoners. *Cognition*, 43, 197–223. doi:10.1016/0010-0277(92)90012-7
- Franco-Watkins, A., Derks, P., & Dougherty, M. (2003). Reasoning in the Monty Hall problem: Examining choice behaviour and probability judgements. *Thinking & Reasoning*, 9, 67–90. doi:10.1080/13546780244000114
- Gilovich, T., Medvec, V. H., & Chen, S. (1995). Commission, omission, and dissonance reduction: Coping with regret in the “Monty Hall” problem. *Personality and Social Psychology Bulletin*, 21, 182–190. doi:10.1177/0146167295212008
- Gluck, M. A., Shohamy, D., & Myers, C. (2002). How do people solve the “weather prediction” task?: Individual variability in strategies for probabilistic category learning. *Learning & Memory*, 9, 408–418. doi:10.1101/lm.45202
- Granberg, D. (1999). Cross-cultural comparison of responses to the Monty Hall Dilemma. *Social Behavior and Personality*, 27, 431–437. doi:10.2224/sbp.1999.27.4.431
- Granberg, D., & Brown, T. A. (1995). The Monty Hall Dilemma. *Personality and Social Psychology Bulletin*, 21, 711–723. doi:10.1177/0146167295217006
- Granberg, D., & Dorr, N. (1998). Further exploration of two-stage decision making in the Monty Hall dilemma. *The American Journal of Psychology*, 111, 561–579. doi:10.2307/1423551
- Heilbrunner, S. R., & Hayden, B. Y. (2016). The description-experience gap in risky choice in nonhuman primates. *Psychonomic Bulletin & Review*, 23, 593–600. doi:10.3758/s13423-015-0924-2
- Herbranson, W. T., & Schroeder, J. (2010). Are birds smarter than mathematicians? Pigeons (*Columba livia*) perform optimally on a version of the Monty Hall Dilemma. *Journal of Comparative Psychology*, 124, 1–13. doi:10.1037/a0017703
- Klein, E. D., Evans, T. A., Schultz, N. B., & Beran, M. J. (2013). Learning how to “make a deal”: Human (*Homo sapiens*) and monkey (*Macaca mulatta*) performance when repeatedly faced with the Monty Hall Dilemma. *Journal of Comparative Psychology*, 127, 103–108. doi:10.1037/a0029057
- Krauss, S., & Wang, X. T. (2003). The psychology of the Monty Hall problem: Discovering psychological mechanisms for solving a tenacious brain teaser. *Journal of Experimental Psychology: General*, 132, 3–22. doi:10.1037/0096-3445.132.1.3

- Lee, D., Conroy, M. L., McGreevy, B. P., & Barraclough, D. J. (2004). Reinforcement learning and decision making in monkeys during a competitive game. *Cognitive Brain Research*, 22, 45–58. doi:10.1016/j.cogbrainres.2004.07.007
- Lenth, R. V. (2016). Least-squares means: The R package lsmeans. *Journal of Statistical Software*, 69, 1–33. doi:10.18637/jss.v069.i01
- Mazur, J. E., & Kahlbaugh, P. E. (2012). Choice behavior of pigeons (*Columba livia*), college students, and preschool children (*Homo sapiens*) in the Monty Hall dilemma. *Journal of Comparative Psychology*, 126, 407–420. doi:10.1037/a0028273
- Nickerson, R. S. (2004). *Cognition and chance: The psychology of probabilistic reasoning*. New York, NY: Psychology Press.
- Page, S. E. (1998). Let's make a deal. *Economics Letters*, 61, 175–180. doi:10.1016/S0165-1765(98)00158-X
- R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Retrieved from <https://www.R-project.org>
- Saenen, L., Heyvaert, M., Grosemans, I., Van Dooren, W., & Onghena, P. (2014). The equiprobability bias in the Monty Hall dilemma: A comparison of primary school, secondary school, and university students. *Proceedings of the Annual Meeting of the Cognitive Science Society*, 36. Retrieved from <https://escholarship.org/uc/item/1m13f1pf>
- Stibbel, J. M., Dror, I. E., & Ben-Zeev, T. (2009). The Collapsing Choice Theory: Dissociating Choice and Judgment in Decision Making. *Theory and Decision*, 66, 149–179. doi:10.1007/s11238-007-9094-7
- Thaler, R. (1980). Toward a positive theory of consumer choice. *Journal of Economic Behavior & Organization*, 1, 39–60. doi:10.1016/0167-2681(80)90051-7
- Thompson, V. A., Evans, J. St. B. T., & Campbell, J. I. (2013). Matching bias on the selection task: It's fast and feels good. *Thinking & Reasoning*, 19, 431–452. doi:10.1080/13546783.2013.820220
- Tubau, E., & Alonso, D. (2003). Overcoming illusory inferences in a probabilistic counterintuitive problem: The role of explicit representations. *Memory & Cognition*, 31, 596–607. doi:10.3758/BF03196100
- vos Savant, M. (1990, 9 September). Ask Marilyn. *Parade Magazine*, p. 16.
- vos Savant, M. (1997). *The power of logical thinking: Easy lessons in the art of reasoning... and hard facts about its absence in our lives*. New York, NY: St. Martin's Griffin.
- [dataset] Watzek, J., Whitham, W., Washburn, D. A., & Brosnan, S. F.; 2018; Replication data for: Responses to modified Monty Hall Dilemmas in capuchin monkeys, rhesus macaques, and humans; Harvard Dataverse; V1; doi:10.7910/DVN/KAGLJU
- Zentall, T. R., Case, J. P., & Collins, T. L. (2015). The Monty Hall dilemma with pigeons: No, you choose for me. *Learning & Behavior*, 43, 209–216. doi:10.3758/s13420-015-0172-3
- Zhao, J., & Yu, R. Q. (2016). Statistical regularities reduce perceived numerosity. *Cognition*, 146, 217–222. doi:10.1016/j.cognition.2015.09.018

**Financial conflict of interest:** This work was supported by National Science Foundation (NSF) grants SES 1123897 and SES 1425216 (to SFB) and the Duane M. Rumbaugh Fellowship from Georgia State University (to JW).

**Conflict of interest:** No stated conflicts.

*Submitted: May 3<sup>rd</sup>, 2018*  
*Resubmitted: July 18<sup>th</sup>, 2018*  
*Accepted: July 30<sup>th</sup>, 2018*

/

## Appendix

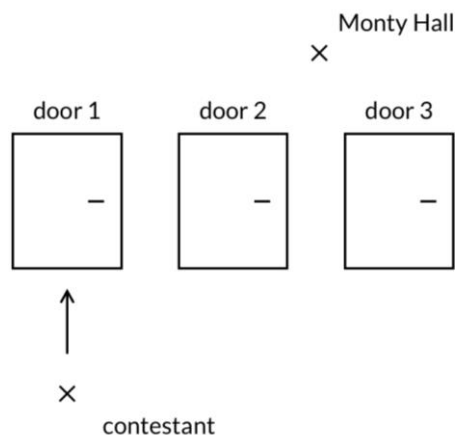
### 3-Door Monty Hall Dilemma

#### LET'S MAKE A DEAL

There is a game show called “Let’s Make a Deal,” where a contestant is allowed to choose one of three closed doors. Behind one door is the first prize, a new car; behind each of the other doors is a goat. After the contestant has chosen a door, the door remains closed for the time being. According to the rules of the game, the game show host, Monty Hall, who knows what is behind the doors, now has to open one of the two unchosen doors and reveal a goat. After Monty Hall shows a goat to the contestant, he asks the contestant to decide whether she or he wants to stay with the first choice or to switch to the last remaining door.

#### Task

Imagine you are the contestant and you don’t know which door the car is behind. You choose a door, say, number one.



In accordance with the rules of the game, Monty Hall then opens another door and shows you a goat. Now he asks you whether you want to stay with your first choice (Door 1) or to switch to the last remaining door.

What should you do?    \_\_\_ stay    \_\_\_ switch

#### Important

Please tell us in writing what went on in your head when you made your decision. You may use sketches, etc., to explain your answer. Feel free to use the back of this page.

Please also tell us if you were already familiar with this game \_\_\_ (Yes) \_\_\_ (No) and knew what the correct answer should be \_\_\_ (Yes) \_\_\_ (No).



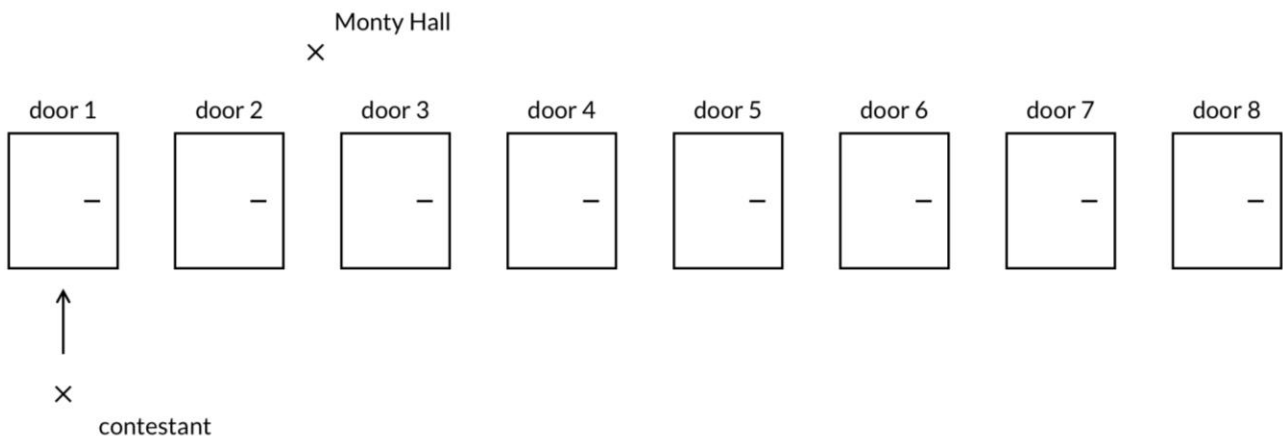
## 8-Door Monty Hall Dilemma

### LET'S MAKE A DEAL

There is a game show called “Let’s Make a Deal”, where a contestant is allowed to choose one of eight closed doors. Behind one door is the first prize, a new car; behind each of the other doors is a goat. After the contestant has chosen a door, the door remains closed for the time being. According to the rules of the game, the game show host, Monty Hall, who knows what is behind the doors, now has to open six of the seven unchosen doors and reveal six goats. After Monty Hall shows the goats to the contestant, he asks the contestant to decide whether she or he wants to stay with the first choice or to switch to the last remaining door.

### Task

Imagine you are the contestant and you don’t know which door the car is behind. You choose a door, say, number one.



In accordance with the rules of the game, Monty Hall then opens six other doors and shows you six goats. Now he asks you whether you want to stay with your first choice (Door 1) or to switch to the last remaining door.

What should you do?    \_\_\_ stay            \_\_\_ switch

### Important

Please tell us in writing what went on in your head when you made your decision. You may use sketches, etc., to explain your answer. Feel free to use the back of this page.

Please also tell us if you were already familiar with this game \_\_\_ (Yes) \_\_\_ (No) and knew what the correct answer should be \_\_\_ (Yes) \_\_\_ (No).