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Authors
Lee, Joanne
Burns, Bruce D

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Convincing people of the Monty Hall Dilemma answer: The impact of solution type and individual differences

Joanne Lee (lees.joanne@gmail.com)
Bruce D. Burns (bruce.burns@sydney.edu.au)
School of Psychology
University of Sydney, NSW 2006 Australia

Abstract

The Monty Hall Dilemma (MHD) is a classic brain teaser that even mathematicians appear to consistently answer incorrectly, and when the correct solution is presented people remain unconvinced. We examined how convincing were three solution types: a simple statement of the solution, a guided diagram solution, or simulated trials. Participants were given the MHD, followed by one of the three types of solutions, then we measured their level of conviction and their numeracy, Cognitive Reflection (CR), Need for Cognition (NFC), and Openness. Overall, both guided diagrams and simulated trials led to higher conviction compared to a simple solution statement. Higher numeracy and higher CR were associated with lower conviction after the simple solution; furthermore higher numeracy tended to help more in the simulation condition, whereas higher CR helped more in the guided condition. Therefore the persuasiveness of a solution depended both on its nature and characteristics of individual reasoners.

Keywords: Reasoning, Monty Hall Dilemma, individual differences, cognitive reflection, belief revision

Introduction

The Monty Hall Dilemma (MHD) is a probability puzzle that involves the reasoner choosing one of three identical doors. One door conceals a prize while the other two doors conceal worthless items. After an initial choice is made, the host, who is aware of where the prize is located, must open a non-chosen door to reveal a worthless item. The participant then has to choose whether to stay with the initial choice or switch to the remaining unopened door. The MHD is named after the host of a television game show *Let's Make a Deal*, Monty Hall, but despite seeming simple its counterintuitive answer has baffled both the general public and expert mathematicians (Friedman, 1998; Granberg & Brown, 1995; Burns & Wieth, 2004). The correct analysis is that switching doors yields twice the chance of winning that staying with the original door does. However, the most common response is that switching or staying does not matter because the probability for winning the prize in either case would be equal, so people stay with their original choice.

The MHD was brought to the public's attention when Marilyn vos Savant described the problem and its correct solution to readers of a newspaper column (vos Savant, 1997). Over 90% of readers' mail argued against the counterintuitive solution, a large number of whom were self-described professors and mathematicians.

Many people who wrongly answer the MHD are highly confident in their wrong answers (Falk, 1992), and what is striking is that people often show a high level of resistance and even impatience upon being shown the correct solution (Rosenhouse, 2009). Some particularly strong responses recorded by vos Savant (1997) included "The switch strategy does not lead to any advantage whatsoever despite vos Savant's mumbo-jumbo of an explanation", and "You blew it, and you blew it big! ... There is enough mathematical illiteracy in this country… Shame!" The present study explores why there is a high level of resistance to the correct solution, and in particular the effect of individual differences on how convincing different solution explanations appear to be.

Resistance and Individual Differences

It is fascinating that some people show a particularly high level of resistance when presented with the MHD solution (vos Savant, 1997), but there is a lack of empirical data examining individual differences. The responses to vos Savant's (1997) solution show that mathematicians and intellectuals can show strong resistance towards the solution, given that 65% of the 10,000 letters written to her were from respondents at universities (Granberg & Brown, 1995). This unsystematic data suggests that an individual difference such as higher numeracy may decrease conviction towards the correct MHD solution. In contrast, measures of better responding to counterintuitive problems (such as *Cognitive Reflection,* Frederick, 2005), and of intellectual curiosity (such as *Need for Cognition*, Cacioppo, Petty, Feinstein, & Jarvis, 1996) may be positively associated with conviction. Finally, the factor of Openness to Experience (McCrae & Costa, 1997) in the five-factor model of personality may also be positively associated with conviction. Therefore we will measure individual differences in numeracy, Need for Cognition (NFC), Cognitive Reflection (CR), and Openness to Experience.

Solutions Descriptions that Decrease Resistance

Conviction in the correct answer can be increased by giving people more elaborate solutions. Quite often the solution to the MHD is in the form of a simple statement or textual description, and people are often resistant to it. Two more in-depth ways of presenting the solution that may increase conviction in the correct answer are: using a computer simulation, or a guided diagram. Intriguingly, it is possible that different individual measures may predict conviction differently dependent on which one of these in-depth solutions is presented.

The literature on belief revision suggests that direct experience contradicting a strong belief can be very important (Markovits & Schmeltzer, 2007). Studies on the MHD have shown that experience in the form of simulation trials facilitates switching doors. For example, Granberg and Brown (1995) found that doing 50 trials of the MHD increased the switch rate from 12% to 55%. In the present study, one of the solution types given was simulated trials with an explicit statement of the solution afterwards, and we expect this to increasing conviction in the correct MHD answer compared to just a simple statement of the solution. However it may be that this solution type will be most beneficial for people with higher numeracy since this solution type provides numerical evidence.

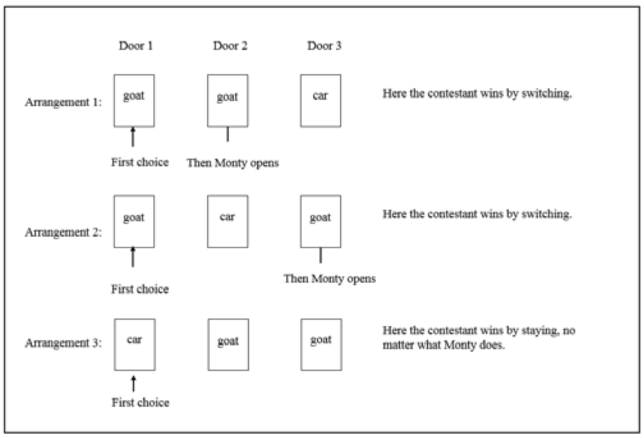

Figure 1: The diagram shown to participants in the guided condition, adapted from Krauss and Wang (2003).

A less numerical solution that may also decrease resistance towards the counterintuitive solution could use guided diagrams. Krauss and Wang (2003) introduced an explanation of the MHD solution that shows three of the possible arrangements in the MHD (illustrated in Figure 1). This explanation has many benefits; it involves participants actually counting the chances of winning and losing and also emphasizes the importance of the host knowing where the prize is rather than the door being opened just by chance. Thus, it addresses the difficulties people have in incorrectly representing the MHD, and clearly shows that the prize would be won in two out of three cases. Such guided diagrams may facilitate intellectual understanding and thus may be particularly effective for those scoring higher on Cognitive Reflection and Need For Cognition, which focus on reflection and intellectual curiosity.

Aims of the Current Study

The current study focused on the effectiveness of in-depth solutions for convincing participants of the correct solution to the MHD, and in particular how individual differences may moderate this conviction. It is anticipated that individual differences will be associated with resistance to the correct solution when given a simple MHD solution. In particular those with higher numeracy skill will display less conviction whereas those with higher CR scores will show greater conviction. Furthermore, we will test how different in-depth solutions may be differentially effective depending on individual differences.

Method

Participants

For this study, 172 first year psychology students from the University of Sydney were recruited for partial course credit. 52 participants were excluded, 37 due to having already seen the MHD, 7 who gave the correct solution at their first attempt, and 8 due to missing data. Excluded participants were replaced in the design, so that the final sample of 120 participants consisted of 100 females and 20 males, with a mean age of 20.02 (*SD* = 5.06).

Independent Variable

Solution Manipulation. Participants were randomly allocated to one of three conditions: simple solution, guided solution or a simulation solution.

1. Simple Solution. In the simple solution condition participants read the following two sentences: “The correct answer is to switch doors, which would lead to a higher chance of winning (2 in 3) compared to if you stayed with the same door (1 in 3). In 2 out of 3 possible car-goat arrangements, the contestant would win by switching”.

2. Guided Solution. In the guided solution condition participants were given a diagram adapted from Krauss and Wang (2003), as shown in Figure 1. This shows the three possible arrangements of the car and goats and subsequent chances of winning. The page also included the same statement given in the simple solution condition.

3. Simulation Solution. In the simulation solution condition participants chose to switch or stay in 50 simulated trials of the MHD, and for each trial the computer determined wins or loses just as a genuine host would. At the end of the 50 trials, the participants were presented with a summary statement of how many wins they had when switching and when staying. They were also presented with the same statement as given in the simple solution.

Dependent Variables

Conviction. The main dependent variable was how convinced participants were of the correct solution. This conviction score was gathered on a 5-point Likert scale in response to the question “How convinced are you that there is twice as high a chance of winning if you switch doors?” ranging from completely unconvinced (1) to completely convinced (5).

Quality of explanation. After their MHD solution was presented participants explained their own answer. This was examined as a dichotomous variable, with two independent raters agreeing on whether the explanation showed some understanding and acceptance of the correct answer, or an expression of confusion and/or disagreement. This qualitative measure of conviction was used to validate the conviction scores.

Numeracy Scores (SN and ON). The Subjective Numeracy (SN) score was calculated with the Subjective Numeracy Scale, adapted from Fagerlin et al. (2007). The scale consists of 8 items each on a 6-point Likert scale, with one reverse coded item. The Objective Numeracy (ON) score was calculated with the Objective Numeracy Scale, adapted from Lipkus, Samsa and Rimer (2001). The scale consists of 11 items, 9 of which ask for a numerical response and the remaining 2 ask to choose from three possible numerical responses.

Cognitive Reflection (CR) Score. The CR score was calculated from the Cognitive Reflection Test, adapted from Frederick (2005). The CR test assess the ability to override a strong incorrect response and reflect further to find the correct response. It has been shown to be a good predictor of task performance on tasks testing for heuristics and biases (Toplak, West, & Stanovich, 2011). The test consists of 3 items, each with a numerical response.

Need for Cognition (NFC) Score. The NFC score was calculated from the short 18-item form of the *Need for Cognition Test,* adapted from Cacioppo, Petty and Feng Kao (1984). This form of the test has been shown to be a valid and reliable measure of an individual's tendency to pursue and enjoy cognitive activities (Cacioppo et al. 1984; Cacioppo et al., 1996). The test consists of 18 items each on a 9-point Likert scale, with 9 reverse coded.

Openness Score and other Personality Measures. The Openness score was calculated using an IPIP Personality Test measuring similar constructs to the NEO-PI-R broad domains, adapted from Goldberg et al. (2006). The test consists of 50 items each on a 5-point Likert scale, half of which were reverse coded items. Of the 50 items, 10 items corresponded to each of the personality variables – Openness to Experience, Conscientiousness, Extraversion, Agreeableness, and Neuroticism.

Time spent on viewing solution. For each solution type, the amount of time spent on viewing or working with the solution was recorded. The main purpose of this was to ensure that the differences in conviction between the solution types were due to the actual solution quality, rather than just the amount of time spent on the solution.

Switch rate in later trials (Simulation Condition only). The switch rate of the last 10 trials was recorded for those given the simulations solution. This could help validate the conviction scores.

Procedure

The experiment was set up as a series of webpages. Participants started by answering demographic questions (gender, age, language spoken at home), then they completed the Subjective Numeracy Scale and the Objective Numeracy Scale. Participants were then presented with the standard Monty Hall Dilemma adapted from Krauss and Wang (2003). They were asked whether they wished to switch or stay, their confidence in their response, probability judgments of both choices, and whether they had seen the problem before.

Participants then received one of three different types of solution: simple, guided or simulation, as described above. All participants were then asked to make probability judgments of winning for switching and staying, to give a short explanation of their responses, and to complete the Likert scale rating for how convinced they were that there is twice as high a chance of winning if they switch doors. Finally, they completed the Cognitive Reflection test, the Need for Cognition test, and a 50 item IPIP personality test.

Results

Preliminary analyses

A preliminary analysis revealed no significant effect of gender on conviction scores nor on any individual difference variables (except for SN); as such gender was not further analyzed or used as a covariate.

There was a significant positive correlation between the quality of the explanation given by participants after being shown one of the three solutions, and their conviction scores; $r(120) = 0.40$, $p < 0.001$. Thus conviction ratings were related to a more descriptive explanation of agreement with the answer. For those in the simulation condition, there was a significant correlation between the switch rate in the last 10 trials and these participants' conviction scores, $r(40) = 0.36$, $p = 0.024$. These findings support the validity of the conviction scores.

Effect of Solution

An analysis of variance was run to examine the effect of the solution manipulation (simple, guided, simulation) on how convinced participants were on the 5-point Likert scale. Mean conviction score was 2.18 ($SD = 1.24$) for the simple condition, 2.80 ($SD = 1.20$) for the guided condition and 3.33 ($SD = 1.14$) for the simulation condition. As expected, there was a statistically significant difference in conviction score as a function of solution type, $F(2,114) = 9.171$, $p < 0.001$.

Planned but non-orthogonal contrasts revealed that the guided solution produced significantly higher conviction scores than the simple solution on average, $F(1,117) = 5.48$, $p = 0.021$. Similarly, the simulation solution produced significantly higher conviction scores than the simple solution on average, $F(1,117) = 18.54$, $p < 0.001$. There were no predictions for differences between the guided and simulation solution conditions, but an exploratory post-hoc contrast analysis was carried out. Even without taking into account that this test was posthoc, the difference was not statistically significant, $F(1,117) = 3.86$, $p = 0.052$.

Time Spent on Viewing Solution. The amount of time spent on viewing the solution was measured as a potential covariate. Overall, time spent on task had a significant correlation with conviction score, as expected; $r(120) = 0.281$, $p = 0.002$. However, time spent on task was not significantly correlated within any of the three solution conditions. This support the claim that difference in conviction score between the three conditions are due to the condition itself and not just to how long participants spend on the solution. However, it was considered that time spent on the solution was potentially a confounding factor for interactions between individual differences and solution type. Time spent on solution fundamentally differed across each solution type, therefore it was added as a covariate in subsequent interaction analyses.

Examination of Individual Differences

The subjective and objective numeracy scales used in this study are known to be closely associated (Fagerlin et al., 2007) and in the current study were found to have a moderate correlation; $r(120) = 0.414$, $p < 0.001$. It was decided it was simpler to focus on one measure of numeracy, and given that SN (but not ON) correlated with gender, $r(120) = 0.198$, $p = 0.030$, it was decided to focus on the objective ON scores.

Table 1: Correlations of conviction with ON and CR Scores, for the 3 solution types (N=40 for each type)

Solution Condition	Conviction/ON	Conviction/CR
Simple Solution	-0.411*	-0.438*
Guided Solution	-0.243	0.146
Simulation Solution	0.098	-0.238

Note: *p < 0.01 (2-tailed)

Correlations between conviction scores and ON and CR scores were calculated for each condition separately (see Table 1). In the simple condition, as predicted, there was a significant negative correlation between ON and conviction scores suggesting that for a simple solution, higher numeracy reduced conviction in the solution. However contrary to predicted, CR and conviction scores were also negatively correlated in the simple condition.

ON and CR scores were positively correlated, $r(120) = 0.397$, $p < .01$. However although none of correlations in Table 1 for guided and simulation conditions were statistically significant, the pattern of correlations for CR and ON differed in an intriguing way. The correlation between conviction and ON is still negative in the guided condition but slightly positive in the simulation condition. However the opposite pattern is observed for conviction and CR correlations, it is negative in the simulation condition but slightly positive in the guided condition.

To test whether individual differences interacted with solution condition in their impact on conviction a series of regression analyses were carried out, one set for numeracy (ON) scores and one set for Cognitive Reflection (CR) scores.

Numeracy (ON) Interactions. To examine the impact of ON scores on conviction regression analyses were conducted first by entering contrasts between the solution types (Model 1) then adding interactions between these contrasts and ON (Model 2). There was no significant main effect of numeracy (ON) on conviction score on its own, $R^2 = 0.031$, $df = 118$, $p = 0.056$.

The interactions between ON scores and conviction were tested as three sets of orthogonal contrast analyses between the solution types where time spent on solution was added as a covariate. These are summarized in Table 2 (Model 2 only). Since there were 3 sets of analyses, α was divided by 3, and thus interactions were significant if they had a p-value was smaller than 0.0167. Table 2 again shows that both guided and simulation conditions had an increased conviction over that observed in the simple condition, but also that there were statistically significant interactions between numeracy and solution type in predicting conviction scores.

Table 2: Summary of regression analyses for conviction scores predicted by interaction of Objective Numeracy (ON) and solution type (N = 120). For space consideration only the Model 2 with the interaction terms is displayed.

	Model 2			
Variable	*b*	*SE*	*β*	*p*
Time spent on solution	-0.00	0.00	-0.39	0.216
ON	-0.18	0.08	-0.20	0.024
Solution condition:				
Simple vs. guided	0.76	0.27	0.25	0.005*
Non-simul vs. simul	1.23	0.56	0.68	0.031
Simple vs. simul	2.22	0.87	0.71	0.012*
Non-guided vs. guided	-0.23	0.29	-0.13	0.427
Guided vs. simulation	1.46	0.83	0.47	0.082
Non-simple vs. simple	-1.00	0.33	-0.55	0.003*
Interactions:				
ON x (simple vs guided)	0.12	0.20	0.05	0.552
ON x (non-simul vs simul)	0.25	0.10	0.21	0.015*
ON x (simple vs. simul)	0.44	0.18	0.21	0.014*
ON x (non-guide vs guide)	-0.07	0.12	-0.05	0.580
ON x (guided vs. simul)	0.32	0.19	0.15	0.099
ON x (non-simple vs simple)	-0.19	0.11	-0.14	0.092
R^2	0.220			
F for ΔR^2	3.389; $p < 0.05$			

Note. Solution type was represented with contrast variables, where 'non-simul' refers to the two solution conditions other than the simulation condition, and similarly with 'non-guided' and 'non-simple'. Since 3 separate analyses were run (each a set of orthogonal contrasts), the critical α values for the contrast effects were divided by 3.
*significant at .05 level if $p < (0.05/3)$.

As suggested by the correlations in Table 1, the analyses in Table 2 shows that there was a statistically significant larger relationship between ON and conviction in the simulation condition compared to either the simple condition or the combination of the two non-simulation conditions. However none of the contrasts with the guided condition were statistically significant. Therefore they suggest that the simulation condition reduced the negative impact of ON scores observed in the simple condition.

Cognitive Reflection (CR) Interactions. The same analyses carried out for ON scores were carried out for CR scores. Again there was no significant main effect of CR scores on the conviction score, $R^2 = 0.028$, $df = 118$, $p = 0.070$. The interaction analyses are summarized in Table 3.

Table 3: Summary of regression analyses for conviction scores predicted by interaction of Cognitive Reflection (CR) and solution type ($N = 120$). For space consideration only the Model 2 with the interaction terms is displayed.

	Model 2			
Variable	*b*	*SE*	*β*	*p*
Time spent on solution	-0.00	0.00	-0.28	0.400
CR	-0.20	0.11	-0.16	0.073
Solution condition:				
Simple vs. guided	0.67	0.26	0.22	0.013*
Non-simul vs. simul	1.05	0.60	0.58	0.085
Simple vs. simul	1.90	0.94	0.61	0.044
Non-guided vs. guided	-0.19	0.30	-0.10	0.538
Guided vs. simulation	1.23	0.89	0.40	0.167
Non-simple vs. simple	-0.86	0.35	0.48	0.016*
Interactions:				
CR x (simple vs guided)	0.70	0.25	0.23	0.006*
CR x (non-simul vs simul)	-0.02	0.16	-0.01	0.882
CR x (simple vs. simul)	0.32	0.28	0.10	0.257
CR x (non-guide vs guide)	0.37	0.15	0.21	0.016*
CR x (guided vs. simul)	-0.39	0.27	-0.12	0.157
CR x (non-simple vs simple)	-0.34	0.15	-0.19	0.027
R^2	0.222			
F for ΔR^2	3.888; $p < 0.05$			

Note. See note for Table 1. $^*p < 0.0167$.

As suggested by the pattern of correlations shown in Table 1 for CR and conviction scores, Table 3 shows that they had a statistically significant stronger relationship in the guided condition verse the simple condition or the combination of the other two conditions. None of the contrast with the simulation condition were significant. Therefore, in contrast to the ON scores, it was the guided condition that reduced the negative impact of higher CR scores observed in the simple condition. This suggests a three-way interaction between condition and CR and ON scores, but we lacked the statistical power for a strong test of that hypothesis.

Need for Cognition (NFC). A linear regression analysis found no significant effect of NFC scores on the conviction score, $R^2 = 0.017$, $df = 118$, $p = 0.156$. There were also no significant interactions between NFC scores and solution.

Openness to Experience. A linear regression analysis found no significant main effect of Openness on the conviction score as expected, $R^2 = 0.005$, $df = 118$, $p = 0.429$, and no significant interactions between Openness scores and solution types in predicting conviction scores. Exploration of scores on other personality variables also found no relationships with conviction.

Discussion

As expected, solution type affected how convinced people were of the answer to the counterintuitive MHD. Both a guided diagram format and a simulation format led to more conviction than a simple text format. Furthermore, in the simple solution condition there were significant negative relationships between conviction and both numeracy and cognitive reflection, thus we supported the anecdotal observation that it is the people usually in the best position to solve probability problems like the MHD that were least convinced by its correct answer.

This study provided evidence that the effectiveness of these solution types interacts with individual differences. The significant negative relationship between numeracy and conviction for those given the simple solution was significantly different compared to the slightly positive relationship between these scores in the simulation solution (although this positive relationship itself was not significant). In contrast, the significant negative relationship between CR and conviction for those given the simple solution was significantly different compared to the positive relationship between these scores in the guided condition. It appears that having higher numeracy or higher CR does not necessarily increase conviction in the simulation and guided conditions respectively, but in the appropriate solution conditions those scores no longer act as much as barriers to conviction as they may have in the simple condition. However, we were not able to perform a strong analysis of the implied three-way interactions on conviction between solution type and the individual differences of CR and ON. Therefore follow-up studies are necessary to test whether the differential impact of these individual differences for different solutions is reliable.

Previous studies have found that simulated trials of the MHD increased the correct switch rate response (Friedman, 1998; Granberg & Brown, 1995; Tubau & Alonso, 2003; Franco-Watkins, Derks, & Dougherty, 2003), and diagrams have been found to assist learning from misconceptions (Marcus, Cooper, & Sweller, 1996; Tubau & Alonso, 2003). We have extended these earlier findings by looking at a measure of conviction specifically, rather than focusing on improved switch rates or answers. We more explicitly measured resistance to the correct answer. However, it is important to note that although both of the in-depth solutions were associated with significantly higher conviction scores compared to the simple solution, the average conviction rating remained below "slightly convinced". As such, there still appears to be resistance despite these more in-depth solutions.

By confirming the possibly harmful effect of numeracy on conviction towards the simply stated MHD solution, our results provide an explanation for why so many of vos Savant's (1997) persistent respondents were mathematicians and professors. Those who have a higher level of numeracy may answer the MHD in a way that is correct according to their inappropriate representation, so their failure is one of representation rather than ability. They may then be more resistant towards the solution knowing that they usually have a high ability to solve mathematical problems.

Cognitive Reflection (CR) scores were predicted to have a positive correlation with conviction but the opposite was found. A higher CR reduced conviction in the MHD when given a simple solution. This is fascinating because the CR test involves solving counterintuitive problems itself, so participants who tended to be better at solving counterintuitive problems were less convinced by a simple solution to the MHD, which is a different counterintuitive problem. This may be because solving the MHD requires more than just a reflection on whether the apparently correct solution is in fact correct, instead a large nonobvious change in its representation is required. Perhaps when the reflection reveals no change, confidence in problem solving ability increases resistance to the correct solution just as it does for numeracy.

There were no significant effects or interactions on conviction scores found between solution type and Need for Cognition (NFC) or Openness to Experience. However we cannot rule out that other measures of these variables may have shown effects.

An implication of the study is that the MHD may be an appropriate model for examining belief perseverance. Past studies on belief perseverance have tended to focus on subjective world beliefs, or fictitious beliefs that are induced experimentally to participants (e.g., Markovits & Schmeltzer, 2007). The persistence and strength of resistance to a mathematically correct answer to the MHD may make it a good task for testing how belief revision occurs.

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