"Probability matching in choice under uncertainty: Intuition versus deliberation"

Probability matching has been characterized as "dumb" (reflecting operations of heuristic judgment) and as "smart" (adaptive in environments in which outcomes may follow patterns). In choices with monetary stakes, we find (a) probability matching persists even when it is not possible to identify or exploit outcome patterns; (b) many "probability matchers" rate an alternative strategy (maximizing) as superior when it is described to them; and (c) probability matchers score lower on the cognitive reflection test than do maximizers. Probability matching is evidently an intuitive response that can be, but often is not, overridden by deliberate consideration of alternative choice strategies.

ARTICLE IN PRESS

Cognition xxx (2009) xxx–xxx

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Brief article

Probability matching in choice under uncertainty: Intuition versus deliberation

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A R T I C L E I N F O

Article history:
Received 27 April 2009
Revised 8 July 2009
Accepted 10 July 2009
Available online xxxx

Keywords:
Probability learning
Probability matching
Dual systems
Judgment under uncertainty
Heuristics and biases

A B S T R A C T

Gaissmaier and Schooler (2008) [Gaissmaier, W., & Schooler, L. J. (2008). The smart potential behind probability matching. *Cognition, 109,* 416–422] argue that probability matching, which has traditionally been viewed as a decision making error, may instead reflect an adaptive response to environments in which outcomes potentially follow predictable patterns. In choices involving monetary stakes, we find that probability matching persists even when it is not possible to identify or exploit outcome patterns and that many "probability matchers" rate an alternative strategy (maximizing) as superior when it is described to them. Probability matching appears to reflect a mistaken intuition that can be, but often is not, overridden by deliberate consideration of alternative choice strategies.

1. Introduction

Consider a simple choice task, in which participants are asked to guess whether a green or a red light will appear on the next trial, and are paid for correct guesses. One outcome appears with a higher probability than the other (e.g., the green light appears on 75% of trials and red on only 25%). Assuming serial independence of outcomes, choosing the more probable outcome on every trial (henceforth referred to as maximizing) is the best strategy in terms of expected payoffs. Instead, however, many people match their choice probabilities to the relevant outcome probabilities (in the example above, predicting the green outcome on 75% of trials and red on the remaining 25%). Because it returns lower expected payoffs, this phenomenon, called probability matching, remains a longstanding puzzle in psychology and economics (for a review, see Vulkan (2000)).

Gaissmaier and Schooler (2008) recently argued that probability matching may be "smart", i.e., an adaptive response to environments in which outcomes potentially follow predictable patterns. In the extreme case, using our earlier example, if there was a consistent, deterministic pattern in the sequence of red and green outcomes, then a participant could exploit it to achieve perfect predictive accuracy (and maximum payoffs), and in doing so would "match" choice probabilities to outcome probabilities. The notion that probability matching is related to a search for patterns has also been suggested by other researchers (Unturbe & Corominas, 2007; Vulkan, 2000; Wolford, Newman, Miller, & Wig, 2004). As evidence for this claim, Gaissmaier and Schooler reported that those participants who used a matching strategy in a standard probability learning task (with serially independent outcomes) were more likely to identify and exploit a pattern when they encountered a sequence that was non-random. By this account, even somebody who recognized that maximizing is the appropriate strategy when faced with a truly random (i.e., serially independent) sequence might engage in probability matching in an attempt to identify and exploit potential patterns in a sequence that might not be truly random.

While Gaissmaier and Schooler's results are suggestive, it remains an open issue the extent to which people

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doi:10.1016/j.cognition.2009.07.003

selectively engage in probability matching in the presence of potential outcome patterns. Clearly the pattern search "strategy" was overextended by their participants to a setting in which there were, in fact, no patterns to be exploited, even after they had observed several hundred outcomes. But perhaps use of a pattern search strategy is restricted to settings in which there is at least the possibility of identifying and exploiting potential patterns. To test this *selective pattern search* hypothesis, we compared choices under conditions in which it either was or was not possible to identify and exploit potential patterns in outcome sequences. If probability matching results from selective pattern search, then it should be less prevalent when pattern information cannot be used.

An alternative interpretation of probability matching is that it is simply a mistake. A specific version of this account, which might be called *expectation matching*, is that probability matching arises from a fast, relatively effortless intuitive assessment (Kogler & Kuhberger, 2007; West & Stanovich, 2003) that generates expected outcomes based on relevant probabilities (Tversky & Kahneman, 1971), e.g., that the green light is expected on 3 of the next 4 trials. Clearly the ability to rapidly generate expected outcomes has adaptive value for many decisions made under uncertainty. Because they come so readily to mind, however, these expected outcomes, in turn, serve as a natural candidate for setting choice proportions, e.g., that one should guess green on 3 of the next 4 trials. This is a form of "attribute substitution" (Kahneman & Frederick, 2002) in which the answer to a relatively difficult question (how many green and red guesses should be made?) is replaced by the answer to an easier one (how many green and red outcomes are expected?). A slower, deliberative evaluation might also be undertaken that could potentially identify an alternative strategy, maximizing, that returns higher expected payoffs. Often, however, the initial intuitive response dominates final choices, either because the participant deliberates very little prior to making the choice, or because such deliberation fails to produce the alternative maximizing strategy (Kahneman & Frederick, 2002). One piece of evidence supporting this dual-system account is that individuals who are higher in cognitive ability, and thereby presumably more efficient in deliberative reasoning, are more likely to maximize and less likely to probability match than are those of lower cognitive ability (Stanovich & West, 2008; West & Stanovich, 2003).[1]

On the expectation matching account, the unavailability of potential pattern information should not influence probability matching behaviour as it is not, by this account, grounded in any kind of search for patterns. Instead, by this account, it is the unavailability of an alternative choice strategy (maximizing), either because deliberation fails to produce it or because the individual fails to deliberate in the first place, that leads to the "endorsement" of the intuitive probability matching strategy in choice behaviour. This raises the possibility that people who probability match in the standard choice task might acknowledge the superiority of the maximizing strategy when it is explicitly presented for evaluation.

2. Method

2.1. Participants

Participants were 120 undergraduate students (53 female) recruited from a campus student centre, who were told that they could receive up to $10 for their participation depending on their performance.

2.2. Procedure

The computer-based choice task was described as a game in which participants were to guess the color of marbles that were to be drawn from a bag containing a mix of red and green marbles. The task consisted of a learning phase followed by a test phase.

In the serial learning condition, participants saw 40 marbles drawn, one at a time, from the bag; in total they saw 30 green and 10 red marbles[2] drawn in a randomized order. This condition allowed participants to search for patterns should they be inclined to do so, though in fact the outcomes were serially independent. In the aggregate learning condition, participants were told that a total of 30 green marbles and 10 red marbles had been drawn from the bag, but they were not presented with trial by trial outcomes and so had no opportunity to observe potential patterns. In both learning conditions, participants were told that each of the 40 marbles had been drawn randomly, with replacement, from the bag.

In the test phase, participants were told that 20 more marbles would be drawn, with replacement, from the same bag, and that they would earn $0.50 each time they correctly guessed the color of a marble drawn from the bag. In the serial test condition, participants were asked to guess the color of each marble drawn, one at a time, without feedback regarding the color that was actually drawn on each trial. The serial test condition allowed participants to order their guesses to follow a pattern, should they choose to do so. In the aggregate test condition, participants were asked to indicate how many times, across the 20 draws, they would guess red, and how many times they would guess green. In this condition, even if participants suspected that that the outcomes might follow some sort of pattern, they had no way to exploit that pattern in making their responses.[3]

[1] Working memory capacity, by contrast, has been found in some probability learning studies (e.g., Gaissmaier, Schooler, & Rieskamp, 2006; Wolford et al., 2004) to be *negatively* correlated with the tendency to maximize, possibly because executing the probability matching strategy across learning trials is more complicated than executing the maximizing strategy.

[2] For ease of exposition, green will be referred to as the dominant color in the task; in fact, the dominant color was counterbalanced across participants.

[3] Subsequently, so that appropriate payoffs could be determined, participants were asked to make a series of serial guesses that maintained the number of red and green guesses they had initially indicated, but they were not aware that they would have the opportunity to do so at the time they indicated, in aggregate, how many times they would guess red versus green.

There were 30 participants assigned to each of the four cells resulting from this 2 (learning: serial versus aggregate) by 2 (test: serial versus aggregate) design.

After finishing the choice task, participants completed a questionnaire in which, among other items, they estimated the overall proportion of red and green marbles in the bag and then evaluated alternative choice strategies. Specifically, a number of strategies were described, including matching and maximizing, that might have been used during a game similar to the one the participant had played, in which it was known that the bag in question contained 70% green marbles. Each strategy was described as having been used by a different hypothetical player, and participants were asked to rank the players in terms of their expected payoffs. After they completed the questionnaire, participants were paid on the basis of their guesses and associated outcomes on the task.

3. Results

Data from 8 participants who made more red than green guesses, or who mistakenly indicated red to be the more probable color in the follow-up questionnaire, were excluded from further analysis, as were data from 10 additional participants who failed to complete the entire study. Overall, participants were largely accurate in their estimates of the probability of drawing a green marble (mean = 70%; SD = 8%).

An index of a participant's tendency to probability match versus maximize was derived by comparing the proportion of times the participant chose to guess green (C) to his or her estimate of the proportion of green marbles in the bag (E, taken from the follow-up questionnaire) as follows:

$$\text{choice index} = (C - E)/(1 - E)$$

This index adjusts for differing perceptions of the probability of drawing a green marble from the bag. Probability matching gives rise to a score of 0 (because $C = E$) and maximizing a score of 1 (because $C = 1$). Negative scores indicate choice probabilities that are lower than estimated probabilities (e.g., participants who made an equal number of green and red guesses despite estimating green to be more probable).

Across all conditions, many more participants engaged in probability matching ($n = 46$ participants with an index value of 0) than in maximizing ($n = 14$).[4] Choices of the remaining participants did not fall in either category by these strict definitions, but the mean value of the index (0.12) and its distribution (see Fig. 1) underscore the appeal of strategies falling close to that expected by probability matching. An analysis of variance on the choice index measure indicated no significant main effects or an interaction between the two experimental manipulations, learning $F(1,98) = 0.003$, $p = 0.96$, $\eta_p^2 = 0.000$; test $F(1,98) = 0.45$, $p = 0.51$, $\eta_p^2 = 0.005$; learning by test $F(1,98) = 1.80$, $p = 0.18$, $\eta_p^2 = 0.018$. There was no evidence that matching was more prevalent when potential pattern information could be identified or exploited.

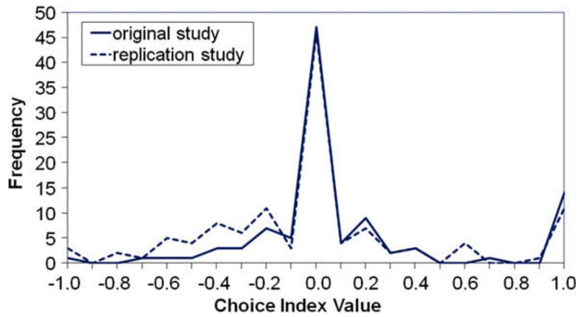

Fig. 1. Distribution of choice index value across participants in the original and replication studies. An index value of 0 indicates probability matching; a value of 1 indicates maximizing.

Responses to the strategy question were categorized in terms of whether the maximizing strategy was ranked higher or lower than the matching strategy with respect to expected payoffs. When explicitly presented with both strategies and encouraged to compare them, many participants ($n = 50$) ranked maximizing as the better strategy; a slightly larger number ($n = 52$) ranked probability matching as better. The proportion of participants who ranked maximizing as superior on the questionnaire is significantly higher than the small proportion who actually used the maximizing strategy in the choice task, $t(101) = 7.12$, $p < .001$. Over 40% of participants ($n = 37$) who used a non-maximizing strategy during the choice task switched to endorse a maximizing strategy on the questionnaire, including 18 of 46 (39%) classified as strict probability matchers on the choice task. Of those participants who maximized on the choice task, only one (7%) switched to the matching strategy.

4. Replication

4.1. Method

These findings were replicated in a nearly-identical second study. Psychology students ($N = 123$) participated for extra course credit rather than for pay, and so the $0.50 payment per correct guess was hypothetical rather than real. The only other substantial change in design was to the learning phase, in which participants now received complete information regarding the contents of the bag. Instead of seeing a sample of 40 marbles drawn from the bag, participants were told that the bag contained 40 marbles and they were going to see the entire contents of the bag. In the serial learning condition, participants saw each marble drawn from the bag (without replacement) one at a time. In the aggregate learning condition, participants were simply provided with the proportion of each color in the bag.

4.2. Results

Data from 2 participants were removed from further analysis using the same criteria as those used in the

[4] A similar pattern of results was found when the raw number of dominant color guesses was used instead as the dependent measure.

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original study. Overall, estimates of the number of green marbles in the bag were roughly accurate with an average frequency estimate of 29 out of 40 marbles (SD = 2.4).

Once again, participants showed an overwhelming degree of strict probability matching across all conditions ($n = 46$ with choice index = 0) as compared to strict maximizing ($n = 11$ with choice index = 1). The mean value of the choice index was 0.002 (see Fig. 1).

Analysis of the index measure indicated no significant effects of experimental condition, learning $F(1{,}117) = 2.40$, $p = 0.12$, $\eta_p^2 = 0.02$; test $F(1{,}117) = 0.00$, $p = 0.99$, $\eta_p^2 = 0.00$; learning by test $F(1{,}117) = 2.02$, $p = 0.16$, $\eta_p^2 = 0.02$. Somewhat more maximizing occurred ($n = 5$) in the serial-serial condition than in the other three conditions ($n = 1, 3, 2$). By contrast, matching occurred most frequently in the aggregate–aggregate condition ($n = 24$), while the other conditions produced lower levels of strict matching ($n = 3, 14, 5$). These marginally significant effects are in the opposite direction from those expected on the selective pattern search hypothesis.

On the questionnaire, a large number of participants ($n = 55$) ranked maximizing as a better strategy than matching; a somewhat larger number ($n = 66$) ranked matching as the better strategy. Again, many more participants endorsed the maximizing strategy when it was presented explicitly than had actually used it during the preceding choice task, $t(120) = 8.0$, $p < .001$. Over 40% of participants ($n = 45$) who used a non-maximizing strategy during the choice task switched to endorse a maximizing strategy on the questionnaire, including 15 of 46 (33%) classified as strict probability matchers on the choice task. Only 1 of the 11 participants (9%) who used a strict maximizing strategy during the choice task switched to endorse the matching strategy on the questionnaire.

5. Discussion

The selective pattern search hypothesis was not supported: participants showed no tendency to switch from probability matching to maximizing under conditions in which patterns could not be identified or exploited. Instead, probability matching was consistently more common than maximizing. Previous research has also reported high levels of probability matching under conditions in which pattern information is unavailable (e.g., Gal & Baron, 1996; Kogler & Kuhberger, 2007; West & Stanovich, 2003). While it is still possible that part of the intuitive appeal of probability matching is linked to a search for patterns, probability matching behaviour is clearly not restricted to settings in which patterns can be identified and exploited, and in this sense is not readily attributed to a selectively applied pattern search strategy.

Our results are more consistent with the interpretation of probability matching as a mistake rooted in a fast, intuitive response that is not reliably overridden by a more effortful reconsideration of whether it in fact produces the highest expected payoffs. Notably, a substantial proportion of participants who engaged in probability matching on the choice task later acknowledged the superiority of maximizing when both strategies were explicitly described for comparison. This suggests that one reason why people engage in probability matching is that it springs readily to mind as a strategy, while maximizing does not.

The literature on probability matching may helpfully be organized by a distinction between the strategy people spontaneously adopt when faced with a choice task of the sort investigated here (where maximizing was very rare), and the strategy they endorse when alternative strategies are provided for comparison (where we found a high rate of endorsement of maximizing). Studies in which choice behaviour is the primary measure (e.g., Edwards, 1961; Tversky & Edwards, 1966; West & Stanovich, 2003, Exp. 3) tend to report lower levels of maximizing than do studies in which the primary measure involves direct comparison of explicitly described strategies (e.g., Gal & Baron, 1996; Stanovich & West, 2008; West & Stanovich, 2003, Exps. 1–2).

Manipulations that can be interpreted as encouraging deliberation, furthermore, such as instructing participants to recommend a strategy to another person (Fantino & Esfandiari, 2002) or to think like a statistician (Kogler & Kuhberger, 2007), have been found to increase maximizing behaviour. Even in the context of probability learning studies in which choice is the primary measure, maximizing behaviour may emerge more readily under conditions that encourage consideration of alternative strategies. Shanks, Tunney, and McCarthy (2002), for example, found that participants moved toward a maximizing strategy when their performance was benchmarked against what could have been achieved by "an optimal strategy", though it took many hundreds of trials before the majority of participants engaged in maximizing. These findings, and ours, suggest that considerable deliberation may be required before the intuition that produces probability matching is overridden by the identification and use of an alternative strategy that yields better returns.

Acknowledgement

This research was supported by a grant from the Natural Sciences and Engineering Research Council of Canada to the first author.

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