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Authors
Guo, Lisa
Trueblood, Jennifer S
Diederich, Adele

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A Dual-process Model of Framing Effects in Risky Choice

Lisa Guo (LISAG1@uci.edu)
Institute for Mathematical and Behavioral Sciences, 2277 Social & Behavioral Sciences Gateway
University of California, Irvine, CA 92617 USA

Jennifer S. Trueblood (JSTRUEBL@uci.edu)
Department of Cognitive Sciences, 2304 Social & Behavioral Sciences Gateway
University of California, Irvine, CA 92617 USA

Adele Diederich (A.DIEDERICH@jacobs-university.de)
Cognitive Psychology, School of Humanities and Social Sciences, Campus Ring 1
Jacobs University Bremen 28759, Germany

Abstract

This work investigates the intuitive and deliberative cognitive processes underlying risky decision-making by manipulating time pressure. A recent fMRI study by De Martino et al. (2006) found greater activation of the amygdala when exhibiting framing effects suggesting that they may be driven by System 1. Because this system is characterized as being fast, we expect more pronounced framing effects under time pressure. In our experiment, we manipulated time pressure and accuracy and use a dynamic dual-process model to explain our results. The model we develop is a sequential sampling model in which the drift rates and boundaries vary in accordance with the thinking modes, frames, and time pressure.

Keywords: Decision-making; dual-process theory; risky choice; time pressure; framing effects

Introduction

Rational theories of decision-making are centered on maintaining logical consistency across decisions (von Neumann, Morgenstern, 1944). However, empirical data has emerged that challenges the "description-invariant" nature of decision-making (Kahneman & Tversky, 2000; McNeil et al., 1982). These empirical demonstrations of description-invariance are termed framing effects (Kahneman & Tversky, 1979, 1981). For example, imagine you are richer by $300 and you have a choice between receiving $100 for sure or playing a gamble with a 50% change to gain $200 and a 50% change to gain nothing. Suppose you prefer the sure option of receiving $100. Now, consider a slightly different situation where you are richer by $500 and have a choice between losing $100 for sure or playing a gamble with a 50% chance to lose nothing and a 50% chance to lose $200. In this situation, you find yourself selecting the gamble. This pattern of choices demonstrates a framing effect because your preferences between the sure option and the gamble change depending on the problem description, even though the expected value of the outcomes is the same.

Researchers have suggested that framing effects are the result of two different systems of reasoning – one that is fast and emotional (the intuitive system) and another that is low and rational (the deliberative system) For example, in a recent neuroimaging study, De Martino et al. (2006) found increased activation in the amygdala when participants exhibited framing effects in decisions between gambles and sure options. They suggested the results support dual-process theory where there is conflict between deliberative processes and an intuitive, emotional amygdala-based system. In general, dual-process theory describes two fundamentally different systems of thought that are involved in the processing and integrating of information. The intuitive system is responsible for fast processes which are affective, emotional, quick, and automatic, while the deliberative system is responsible for slower processes that are more analytical, rational, slow, and calculating in nature (Chaiken & Trope, 1999; Sloman, 1996; Kahneman & Frederick, 2002; Mukherjee, 2010). The former system is also known as System 1, while the latter system is commonly referred to as System 2 (Stanovich & West, 2000).

This paper aims to further investigate dual-process explanations of framing effects in risky decision-making and to test a novel prediction regarding time pressure. If framing effects are attributed to the intuitive system, then we expect more pronounced framing effects under time pressure because this system is characterized as being quick and automatic. We test this hypothesis in a new experiment and develop a dynamic dual-process model to account for our results. Specifically, we formalize the underlying cognitive processes as a sequential sampling model that accounts for differences between the deliberative and intuitive systems by changes in the evidence accumulation process.

Experiment

Similar to De Martino et al. (2006), our present study involved a risky decision-making task. Participants were given a message indicating an initial amount of money that they would receive on each trial. They then had to choose between a sure option and a gamble, with the sure option presented in either a gain or a loss frame. In both frames, the gamble was identical (i.e., had the same expected value) and presented as a pie chart color-coded to represent the probability of winning and losing. Apart from using a single-colored pie chart to represent the sure option, our experiment differed from the study by De Martino in two major respects. First, we introduced an aspect of time pressure for one of the two blocks as this was deemed to invoke the intuitive system. Second, we provided feedback for participants' choices depending on whether or not they were currently in a time pressure block. This reinforced the presence or absence of the time pressure and allowed participants to track their progress depending on the goals of each particular block.

Method

Participants Forty-nine individuals (40 Female; M=20.65 years) from the University of California, Irvine participated in the study, receiving course credit for their participation (regardless of performance). All participants were undergraduate students and were native English speakers.

Materials Eighty randomly generated amounts between $20 and $90 were used for the initial starting values. Eighty randomly generated percentages (mean = 0.5, std = 0.2) were generated to serve as the probabilities of winning and losing for the gamble. From these values we created the sure option for each trial to match the expected value of the gamble, depending on frame. For instance, for an initial amount of $64 and a winning gamble percentage of 0.56, the sure option would either be "Keep $36" (gain frame) or "Lose $28" (loss frame).

Ten percent of the total trials (i.e., 32 trials) were collected to assess accuracy. These catch trials had non-equivalent "sure" and "gamble" options in which one option was clearly superior. The experiment was comprised of two blocks, each block consisting of 160 trials: eighty gain frames and eighty loss frames, for a grand total of 320 trials. All choices and response times were recorded, as well as participants' age and gender.

Framing Effect We are interested in the framing effect that occurs with risky decision-making between the sure and gamble options. For this experiment, a framing effect occurs for a participant when a) in the gain frame, the decision-maker chooses the "sure" option; and b) in the loss frame, the decision-maker chooses the "gamble" option. Thus, we categorize risk-averse behavior in gains and risk-seeking behavior in equivalent losses as a framing effect.

Time Pressure The two blocks were differentiated by the presence or absence of time pressure. One block is a speed block (SPD) where participants are told that their goal is to "Respond quickly" and for each trial, are given 1000 ms to make a choice. Since the task involves earning money, a latent but unwritten goal of the SPD block is to earn money. However, to ensure time pressure, the only directions given to participants in the SPD block were to "Respond Quickly." If they fail to make a choice within this amount of time, they receive a feedback message that states that they did not respond in time and did not earn any money on that particular trial. If the participant makes a choice within the allotted time frame, they do not receive any feedback on that trial.

The other block is an accuracy block (ACC) with no time pressure. For this block, participants are told that they should "Maximize their money" and are not penalized for the amount of time they take to respond. In this block, we provide feedback after every trial explaining the amount of money earned on that trial. This reinforces the initial goal of maximizing their money by emphasizing the money earned on each trial.

Procedure The two blocks and the 160 trials in each block were randomized. As shown in Figure 1, each trial began with the presentation of an initial amount (e.g., "You are given $64") and the goal for that block (e.g. "Respond Quickly"). Participants were instructed that they were not able to retain the entirety of the initial amount, but would have to choose between a sure option and a gamble option. 1000 ms after the initial amount was displayed, the screen automatically progressed to this choice screen. In the gain frame, the sure option was presented on the left side of the screen as an amount retained as a 100% green pie chart (Figure 1A) (e.g., "Keep $36"). In the loss frame, the sure option was presented on the left side of the screen as an amount lost in a 100% red pie chart (Figure 1B) (e.g., "Lose $28"). For both the gain and loss frames, the gamble option was identically presented on the right side of the screen as a pie chart representing the probability of keeping the entirety of the initial amount (in green) or losing the initial amount (in red).

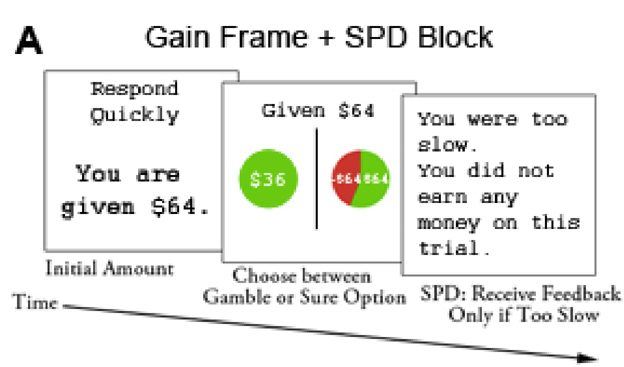

Figure 1A: Timeline of a single trial. Possible progression of a gain-frame trial in the speed block

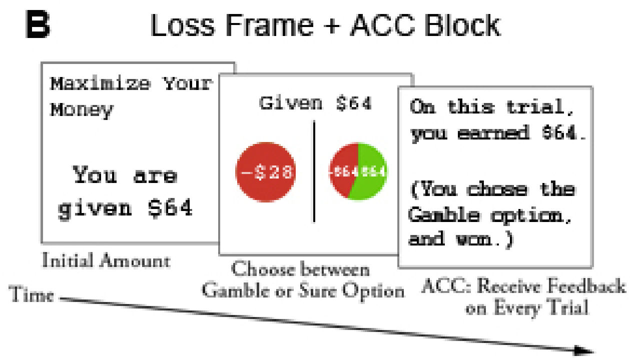

Figure 1B: Timeline of a single trial. Possible progression of a loss-frame trial in the accuracy block

Results

We analyzed the results from all 49 participants. The average proportion of catch trials answered correctly was 0.884. A scatterplot of the overall proportion of framing effect choices is shown in Figure 2. We see that there is a greater proportion of framing effect choices occurring in the SPD block (red dots; 33 out of 49, 0.67) compared to the ACC block (blue triangles; 16 out of 49, 0.33). The mean proportion of framing effect choices in the ACC block was 0.64 and for the SPD block was 0.71 (t(48) = 4.25, p < 0.001). The mean reaction time for the accuracy block was 1366 ms (std=756 ms) while the mean reaction time for the speed block was 494 ms (std=112 ms).

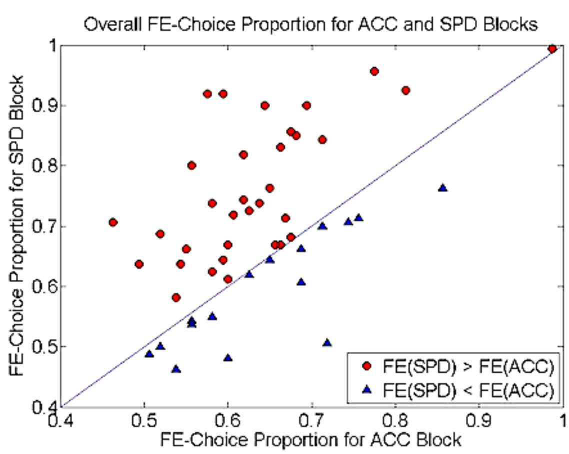

Figure 2: Overall proportion of framing effect (FE) choices for SPD and ACC blocks. Red dots indicate participants who displayed a greater proportion of framing effect choices in the SPD block; Blue dots indicate participants who displayed a greater proportion of framing effect choices in the ACC block. The diagonal line indicates the equivalent proportion between SPD and ACC.

We did not find a significant effect of *frame* (gain and loss) with regard to the framing effect. The difference between the mean proportion of framing effect choices for the gain frame (0.67) and the loss frame (0.68), (t(49) = 0.31, p = 0.88) agrees with De Martino's study as well.

Table 1: Results from a Within-Subjects Repeated ANOVA as a function of Frame and Block.

Factor	Result
Frame (Gain/Loss)	F(1,48) = 0.02; p = 0.88
Block (ACC/SPD)*	F(1,48) = 18.1; p < 0.0001
Frame × Block	F(1,48) = 0.56; p = 0.46

* Results remain significant even when accounting for block order (randomized for each subject).

We examined the influence of two factors (*frame* and *block*) on the framing effect as shown in Table 1 and Figure 3. The main effect of *frame* in Table 1 was not significant (gain-ACC proportion 0.62 vs. loss-ACC proportion 0.65; gain-SPD proportion 0.71 vs loss-SPD proportion 0.70) but the main effect of *block* was significant (gain-ACC 0.62 vs. gain-SPD 0.71; loss-ACC 0.65 vs. loss-SPD 0.70).

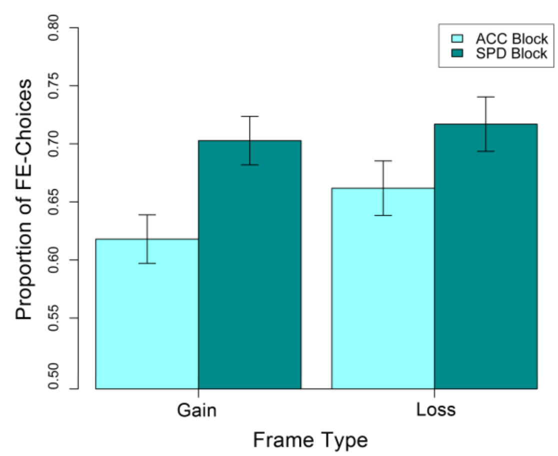

Figure 3: Overall proportion of framing effect (FE) choices split by block and frame. Results indicate a significant effect of *block* (ACC/SPD) on framing effect choices. Error bars represent standard error of the mean proportions.

Discussion

Using a risky decision-making task, the present experiment investigated how framing and time pressure affect decision-makers' choices, with a focus on the framing effect (i.e., choosing the sure option for gains and choosing the gamble for losses). The results showed more participants displaying a framing effect more frequently in the speed block (with time pressure) than the accuracy block. This adds to a growing body of literature suggesting that a framing effect might be driven by the intuitive system.

Our current experiment fixes the location of the sure option on the left side of the screen, and the gamble option on the right side of the screen. Future versions of this experiment might include a randomization of these locations.

Modeling

We developed a sequential sampling model that assumes a separate sampling process for the intuitive and deliberative systems. Our model is an extension of the multiattribute attention switching (MAAS) model (Diederich, 1997; Diederich & Oswald, 2014), which predicts rich patterns of choice probabilities including preference reversals. In our extension of the MAAS model, drift rates are defined as

$$d = V_G - V_S \tag{1}$$

where V_G is the subjective value of the gamble and V_S is the subjective value of the sure thing as calculated by prospect theory (Tversky & Kahneman, 1992). For an option j, the subjective value is the sum over the weighted values of each outcome:

$$V_j = \sum_i w(p_i)v(x_i) \tag{2}$$

where $w(p_i)$ is the decision weight for outcome i with probability p; and $v(x_i)$ is the value function applied to outcome i and amount x. The decision weights are defined as:

$$w(p) = \frac{p^c}{(p^c+(1-p)^c)^{1/c}} \tag{3}$$

where the c parameter represents positive payoffs. Values of these parameters that are nearer to 1 indicate more linear perceptions of probability.

The prospect theory value function is defined as:

$$v(x) = \begin{cases} x^\alpha \ if \ x \geq 0 \\ -\lambda|x|^\beta \ if \ x < 0 \end{cases} \tag{4}$$

We assume there are two drifts; one associated with the intuitive system and one associated with the deliberative system. We use the equations above to calculate the drift rates for both systems, but allow for different parameter values (i.e., α, β, λ, and c) for the two systems. Further, we assume that the intuitive system precedes the deliberative system so that there is a switch in drift rates during the course of a trial (i.e., the two systems are acting sequentially, with the intuitive system acting first). We assume the intuitive system operates first because it is characterized as being quick and automatic.

Figure 4 shows three different simulations of a loss-frame trial: choosing the gamble (upper, positive boundary) or choosing the sure thing (lower, negative boundary). In this process, evidence accumulates over time until it crosses one of the two boundaries. The speed with which the evidence accumulation process approaches one of the boundaries is the drift rate, with a positive drift rate approaching the gamble boundary and a negative drift rate approaching the sure thing boundary. The separation between the two boundaries determines the amount of evidence that must be accumulated before a decision is made. We assume that the difference between the thresholds is smaller for the speed condition (SPD in Figure 4) and larger for the accuracy condition (ACC in Figure 4). For sequential sampling models, previous research has shown that the difference between speed and accuracy conditions is typically explained by a change in the boundaries (Ratcliff & Rouder, 1998). At some point $t > 0$, there is a switch from the intuitive to the deliberative system, after which the evidence accumulation continues until a boundary is reached.

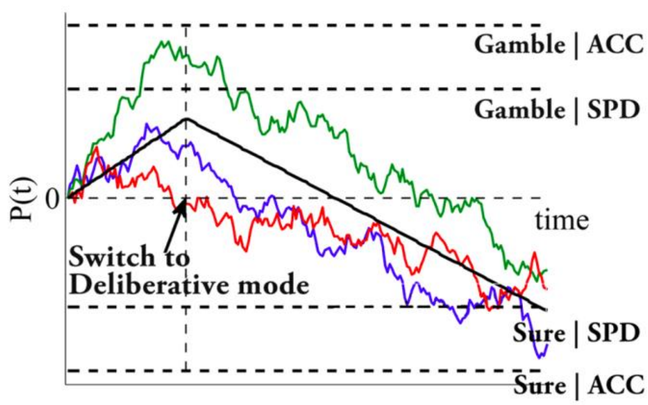

Figure 4: Simulation of the loss frame. The trajectories symbolize the accumulation process for three different loss trials. In one trial (green) the process reaches the boundary for choosing gamble under the speed condition before the switch occurs. In the other trials (red and blue) the process reaches the boundary for choosing the sure option under the speed condition after the switch.

We illustrate that our model can capture the main experimental result of increased framing effects under time pressure by applying it to one set of choices from the experiment as shown in Figure 1 and Table 2.

Table 2: Sample trial used for modeling

Type of Amount	Amount
Reference point ("You are given $")	64
Sure Gain ("Keep $")	36
Sure Loss ("Lose $")	28
Gamble amount ("Keep All $")	64
Probability of Gain (probability of "Keep All $")	0.56

We set the parameter values for the sample trial above as shown in Table 3. Parameter values for the intuitive system were based upon Tversky & Kahneman's prospect theory values (1992). These parameter values were used by Tversky and Kahneman to account for a wide range of choice behavior including the fourfold pattern of risk attributes, which includes framing effects similar to the ones discussed in this paper. Because the deliberative system is characterized as being rational, we set the parameter values to 1 so that subjective values were the same as expected values.

Table 3: Parameter values used for modeling.

Intuitive system	Deliberative system
$\alpha_I = 0.88$	$\alpha_D = 1.00$
$\beta_I = 0.88$	$\beta_D = 1.00$
$\lambda_I = 2.25$	$\lambda_D = 1.00$
$c_I = 0.61$	$c_D = 1.00$

To incorporate the reference point, denoted by r, we assume the subjective value of the gamble is:

$$V_G = w(p_+)v(r)$$

where p_+ is the probability of keeping this amount. For gambles, participants either receive r or 0 and $v(0) = 0$. Because the gamble is described the same way in both the gain and the loss frames (that is, participants see the same pie chart), we assume that V_G is the same in both frames.

However, the sure option is described differently in the two frames. In the gain frame, participants are told they can keep s and in the loss frame, they are told that they will lose $l = r - s$. To capture these differences in framing, we assume that the subjective value of the sure thing in the gain frame is:

$$V_S(s) = v(s) \quad (5)$$

and in the loss frame is:

$$V_S(r - l) = V_S(r) + V_S(-l) = v(r) + v(-l). \quad (6)$$

Note that the decision weights are equal to 1 since there is no risk or uncertainty involved in the sure option.

For the example gamble described in Table 2, we searched over different switch times (i.e., amount of time spent in the intuitive system before switching to the deliberative system) between 3 and 1000 ms and over different values for the difference between the thresholds between 2 and 10. Figure 6A shows a heatmap plot of the probabilities of choosing the gamble for the gain frame. We see the expected trends that illustrate the framing effect: as the difference between bounds decrease (i.e., corresponding to increased time pressure), the probability of choosing the gamble decreases (i.e., the sure option is selected more often). Also, as the switch time increases (i.e., spending more time in the intuitive system), the probability of choosing the gamble decreases. Similarly, Figure 6B shows the probabilities of choosing the gamble for the loss frame. Again we see the expected framing effect: as the difference between bounds decreases, the probability of choosing the gamble increases for losses. As the switch time increases, the probability of choosing the gamble increases.

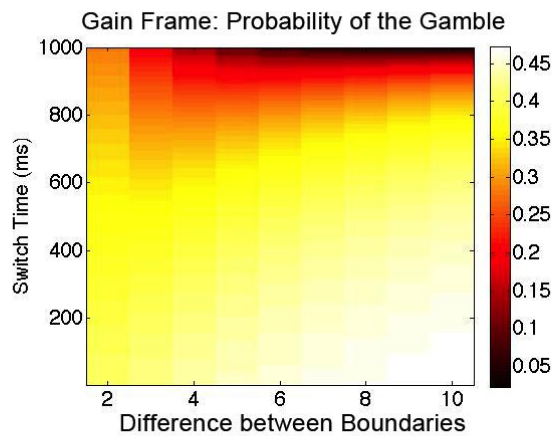

Figure 6A: Heatmap showing the probability of choosing the gamble for gains, searched over different switch times and differences between boundaries

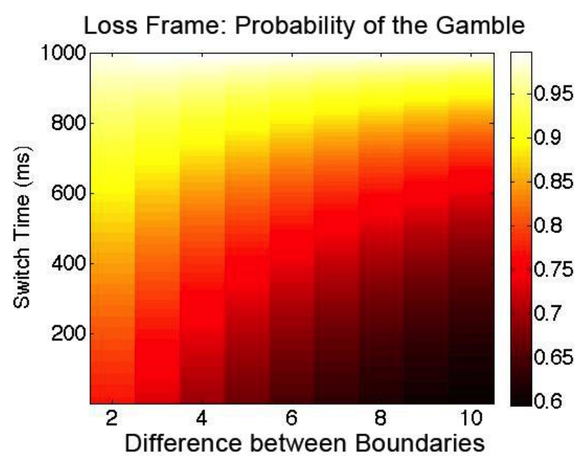

Figure 6B: Heatmap showing the probability of choosing the gamble for losses, searched over different switch times and differences between boundaries

Discussion

Using a risky decision-making task and the element of time pressure, the present experiment investigated the framing effect and its relationship to dual process theory. The results from our study show that there was a greater occurrence of the framing effect when decision-makers were put under time pressure. These results add to a growing body of literature suggesting that framing effects are driven by the intuitive system.

The present results extend the findings from De Martino et al. (2006), but using a different presentation of options (a pie chart for the sure option in addition to the gamble option), a feedback system, and most importantly an element of time pressure that allowed for distinguishing between a fast, emotional response and a deliberative, calculated response.

Most past dual process models have been verbal models, which do not provide exact predictions. Our model is one of the first formalized accounts of dual systems of reasoning. Further, our model is dynamic, taking into account the timing of the two systems. In our approach, we use a sequential sampling model where the intuitive and deliberative systems are associated with different evidence accumulation processes. Such a model is able to take into account the two different cognitive processes of the intuitive and the deliberative system, as well as incorporate a switch in the sequential processing of the intuitive to the deliberative system. Our model explains the framing effects found in both our studies and previous findings.

In our model, the intuitive and deliberative systems are distinguished by a change in the evidence accumulation process, as captured by different drift rates. However, both systems are assumed to follow the same valuation process as defined by Prospect Theory. The idea that the two systems use the same valuation process connects with work by Glöckner and Betsch (2008) showing that the weighted additive rule (WADD) of utility theory can account for both decisions made by automatic processes driven by the intuitive system and those made by the deliberative system. Thus, it is not necessary to characterize the two systems as using separate decision strategies. As shown in the current paper, differences between intuitive and deliberative systems can be accounted for by simply allowing for changes in how evidence is accumulated during the time course of the decision.

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