Effort and Delay Discounting in a Foraging Environment 2

Claudio Toro-Serey & Joseph T. McGuire

## 

## Research Questions

#### 3.1. Main question: Are decisions affected differently by equivalent time periods of pure delay, cognitive effort, and physical effort? Crucially, is this pattern different when individuals chose among all forms of effort?

## Hypotheses

#### 4.1. Single-option, accept/reject decisions will be influenced by within-subject manipulations of reward magnitude in line with a theoretical reward-maximizing strategy.

**4.1.1.** Participants will more frequently accept high-reward prospects than low-reward prospects. **4.1.2.** The pattern of acceptances will match that of groups that previously experienced each effort separately for an equivalent period of time.

#### 4.2. Prospect acceptance rates will differ across three within-subject conditions, in which the delays associated with rewards (a) are unfilled, (b) include a cognitive effort requirement, or (c) include a physical effort requirement. Each effort type will be paired with unfilled delay trials in a blocked manner.

**4.2.1.** Acceptance rates for unfilled-delayed trials will be higher than those for both physical and cognitive effort trials.

**4.2.2.** Acceptance rates for physical effort trials will be lower than those for cognitive effort trials.

**4.3.3.** Acceptance rates for unfilled-delay trials will not differ based on their pairing with each effort condition.

#### 4.3. Choices will be well fit by a computational model in which the subjective opportunity cost of time is free to vary across the four between-subject conditions.

**4.3.1.** Participants will display stable preferences, meaning that the reward amounts they accept in a given cost condition will be similar throughout the experiment.

**4.3.2.** Subject-specific opportunity cost (OC) estimates will vary inversely with acceptance rates. Thus, the unfilled-delay condition will produce higher OC estimates than both effort conditions, which in turn will show no differences between them.

## Analyses

#### 16.1. Tests of whether decision makers integrate reward information.

**16.1.1.** *To address hypothesis 4.1., A logistic regression will be fit for each participant in order to predict trial-wise acceptances, using reward amount as predictor. The resulting beta coefficients will be pooled across all participants, and we will perform a one-sample rank-sum test on each set of coefficients to examine whether the they are significantly positive or negative (compared to 0). If the group coefficients are significantly positive, it would mean that a predictor reliably increases the likelihood of acceptance. This will allow us to determine whether increments in reward amounts increased the likelihood of acceptance for each participant.*

**16.1.2.** *We will perform an extension of the logistic regression from 16.1.1., this time adding an autoregressive covariate containing the number of consecutive quits prior to a given trial. In this way, we will examine the possibility that participant choices were governed by recent quitting history rather than the experimental parameters (see 11.1.3.). Coefficients not significantly different from 0 will denote that a participant did not rely on recent quitting history.*

**16.1.3.** *A general linear model with constant, linear, and quadratic terms will be used to estimate the correspondence between proportion accepted (independent variable) and total earnings (dependent variable). No other covariates will be used, as this analysis is to confirm that over and under accepting are detrimental to total earnings.* ***The quadratic term will be defined as the squared deviation from the optimal overall acceptance rate?***

**16.1.4.** *To determine the optimality of the group’s decisions, we will perform two-sided one-sample t-tests to see if the proportion of acceptances for each time/reward combination was significantly different from the optimal rate (see 11.2.). This will result in 12 independent tests (3 reward amounts, and 4 cost types), so we will correct for multiple comparisons using False Discovery Rate (FDR).*

#### 16.2. Comparisons among the four delay and effort conditions.

**16.2.1.** *To compare preferences (hypothesis 4.2.), we will first perform a one-way ACNOVA on the proportion of trials accepted using cost as a factor (using subject as a covariate). In addition, we will do pairwise comparisons on the proportion completed among all 4 cost conditions using non-parametric permutation contrasts (6 tests). The same approach will be used for total earnings. This will give us an initial glimpse on the potential differences in cost among conditions. (****Maybe just do 16.2.3.)***

**16.2.3.** *We will compute the probability of accepting a trial with a mixed-effects logistic regression. Based on the task structure and our main question, our a priori model of interest will include cost condition and reward amount as fixed main effects, and subject ID as a random effect. Cost condition will be modeled with three categorical terms, with the fourth condition as the reference condition. We will run three versions of the model with different reference conditions, in order to test all pairwise differences among the four cost conditions. We anticipate significant main effects (coefficients different than zero) reward and cost condition. We hypothesize that the differences among cost conditions will follow the pattern described in 4.2. (****Think about the random-fixed organization, and whether the cost 2 one makes sense. Maybe this one should be random intercepts AND slopes)***

**16.2.4.** *Next, we will examine whether the a priori model from 16.2.3. outperforms both simpler and more complex models. Unlike the individual logistic regression fits in 16.1.1., a mixed-effects approach gives us a better goodness of fit measure for model comparisons. We will determine the best model (combination of predictors) using Akaike’s Information Criterion (AIC) to determine the model that minimizes the negative log-likelihood while penalizing the addition of parameters. The regression with each combination of predictors will be fitted in the following order: 1) intercept only; 2) condition only; 3) reward only; 4) condition and reward main effects (from 16.2.3.); and 6) adding a two-way interaction. We predict that model 4 will have the lowest AIC.*

#### 16.3. Modeling the subjective opportunity cost in each condition.

**16.3.1.** *Response times (RT) for quit responses will be presented in a descriptive manner in order to examine whether participants tended to quit early or late within individual trials. Each cost condition’s response time distribution will contain the pooled RT across participants, and we will display the empirical cumulative distribution functions for each condition. Short RT would suggest confident and stable decisions (in support of 4.3.1.).*

**16.3.2.** *We will also compute the proportion of quits that were performed during the choice window versus during the handling time. If over 80% of quits occurred during the choice window on average, this will suggest that participants were confident in their choices.*

**16.3.3.** *In order to further examine choice stability (hypothesis 4.3.1.), we will compute each participant’s total proportion of acceptances pre- and post-midpoint. We will compute a mixed-effects linear model to predict post-midpoint proportion of acceptances from pre-midpoint rates, with subjects as random intercepts and condition as a dummy-coded fixed effect. We will report the 95% confidence interval (CI) of the intercept (the reference dummy-coded condition) and the significance of the coefficients for the remaining conditions. A CI containing 1 will denote that participants in that condition produced consistent choices, while accounting for the overall acceptance patterns of a given subject across conditions. We will rotate the dummy code to explore whether any condition produced significantly different pre-post acceptance rates (****alternatively, we can remove the intercept from the mixed model to get the actual coefficients + CIs****).* ***Option 2:*** *we will perform a repeated measures ANCOVA, with condition as factors and subject as a covariate.* ***Simple option 3:*** *We will compute a linear model predicting post-midpoint acceptance rates from pre-midpoint acceptance rates as well as condition. We will regress out the effect of subject.*

**For the next 2, think about how to add a modulatory element to include cost type**

**16.3.3.** *To estimate the subjective opportunity cost (hypothesis 4.3.2.), we will use a logistic function to model each participant’s probability of completing a trial based on the difference between the delayed reward’s magnitude and the estimated opportunity cost (OC) for each cost type. OC will be computed as the product of a free parameter (gamma) and the handling time. Both gamma and the temperature parameter of the logistic function will be estimated at the subject level, independently for each subject.*

**16.3.4.** *We will cross-validate each subject’s OC value using the pre-midpoint data for estimation, and post-midpoint choices for testing. The estimates will be used to predict acceptances in the testing sample, and the mean percent correctly predicted will be reported for each group. This will also provide information on the stability of each participant’s choices (4.3.1.).*

**16.3.5.** *The OC estimates for each group will be compared using an ANOVA with condition as a factor. This will let us determine which cost type produced the highest discounting.*

**5. Existing** **data**:

Registration prior to creation of data

**6. Data collection**

The study will use human subjects recruited from the university community, who will be recruited through the university job board. We will pay up to $30 for a session (1 hour), which includes incentive-based rewards. Participants will be ineligible if they have participated in our pilot study, or they are under 18 years of age. The study will run for however long it takes to reach our desired sample size.

**7. Sample size**

We will acquire a sample of XX participants.

**8. Sample size rationale?**

Sample sizes were determined by means of power analysis (ANOVA), using a significance level of 0.05, power of 0.8, an effect size of f = 0.45 (calculated from a pilot study), and three groups (one for each condition). The resulting per-group sample was 20, which we will round up to 21 in order to match the potential order of timing conditions (15.2.). We added an extra group of 21 participants who will experience a minimally effortful condition in order to determine whether effort or pure engagement were driving our results.

**9. Variables**

9.1 The present study has three levels of manipulation.

9.1.1. Cost condition, manipulated within subjects. The conditions are (a) unfilled delay, (b) cognitive effort, and (c) physical effort. Unfilled delays will be paired with each effort type in a blocked manner (7-minute blocks). Each combination will be experienced three times.

9.1.2. Handling and travel times. These will dictate how long each trial is. The "handling time" governs how long it is necessary to wait or work to obtain a reward if a trial is accepted. The "travel time" governs how long the inter-trial interval will be, regardless of whether the trial is accepted. Participants will know that the handling time will be always 10 seconds, and the travel time 6 seconds (matching one of the between-group experiment conditions).

9.1.3. Reward magnitude, manipulated within-subject across individual trials. On each trial, participants will learn the amount of money they can earn if they complete the trial (i.e. 4, 8, or 20 cents). The amounts will be sampled uniformly, while guaranteeing that each participant experiences each amount at least twice during each block.

**10 Measured variables**

10. Measured variables

10.1. Behavioral variables

10.1.1. Choice (complete or quit a given trial).

10.1.2. Response times.

10.1.3. Total earnings.

10.1.3. Performance in the cognitive effort tasks (right or wrong answer).

10.1.4. Grip force throughout the experiment and maximum grip strength (physical effort condition).

10.2. Questionnaire

10.2.1. Age.

10.2.2. Gender.

10.2.3. Post-experimental oral assessment of choice strategy adoption. We will ask participants the following: “Did you follow a specific acceptance strategy? If so, what was it?” Answers will be written down by the experimenter, and recorded on an excel spreadsheet.

**11. Indices**

11.1. Behavioral data

11.1.1. We will compute the proportion of prospects accepted.

11.1.2. Percentage of cognitive effort trials with above-threshold errors (over 2 errors), in which participants are forced to travel to the next trial.

11.2. Optimal behavior

11.2.1. The theoretical opportunity cost of time will be calculated for each handling/travel/reward acceptance combination in order to assess choice optimality. This measure is computed as the cents per second possible when consistently accepting only certain reward amounts (e.g. 8 and 20 cents) in a given timing condition. This ground truth measure is independent of cost type, allowing us to assess subject optimality.

**12. Study type**

Experiment - A researcher randomly assigns treatments to study subjects, this includes field or lab experiments. This is also known as an intervention experiment and includes randomized controlled trials.

**13. Blinding**

No blinding is involved in this study.

**14. Study design**

14.1. The present study complements our previous one, which evaluated cost types using a between-group design. Many of the details remain the same. However, this time every participant will experience all forms of cost (delay, physical effort, and cognitive effort). Delay trials will be intermixed with both physical and cognitive trials, providing a common condition to compare these effortful costs. On each trial, participants will have the opportunity to either wait or work for 10 seconds (the "handling time") in order to earn a reward; alternatively, they can quit and skip to the next trial (which incurs a 6 second travel time). Two types of trial combinations (physical/wait and cognitive/wait) will be experienced three times by each participant in 7-minute-long, interleaved blocks. Reward amounts can be 4, 8, or 20 cents, uniformly distributed. Timing information will be disclosed at the beginning of each block, and rewards displayed before each trial begins.

**15. Randomization**

15.1. Block type: Each block will contain unfilled delay trials and trials of one effortful cost type (se 14.1). Blocks with each cost type will be interleaved, and participants will be assigned to one of two orders: beginning with a cognitive/wait or a physical/wait block. A row will be assigned to subject IDs prior to recruitment, ensuring that each order is experienced equally often. Participants will be offered a break after performing three out of the six blocks.

15.2. Rewards and cost type: Participants can earn 4, 8, or 20 cents per trial at the cost of performing one of the three conditions. These values are sampled without replacement from a vector containing every combination of cost (effort defined by the current block, and delay) and reward. The vector is reshuffled once completed. This ensures that each combination of cost and reward is presented at least twice per block.

15.3. Trial color: during the offer phase, each cost type will appear in a unique color in order to ease its identification. Colors were chosen to have a good amount of contrast while being amenable to red-green color-blindness. Colors will be assigned to each cost type so that all three colors are equally paired to each cost type across participants. A row will be assigned to subject IDs prior to recruitment to indicate their block order and color pairing.

**17. Inference criteria**

These criteria will remain the same as before. For the ANOVAs, we will report the F statistic as well as the p-value. For the multiple linear regressions and logistic regression, we will report the betas (coefficients) and their associated p-values. When comparing two groups of values as in pairwise comparisons, we will use non-parametric permutation tests. We will report p-values and all tests will be two-tailed. The alpha threshold for p-value evaluation will be set at 0.05.

**18. Data exclusion**

18.1. Missing data and quitting early. Participants are told that they are allowed to stop participation in the study at any time without consequence. Data from participants who do not finish the experiment will be excluded from the study, and those participants will be replaced.

18.2. To guard against inattentiveness, a single 30 second catch trial will be placed at the end of each experimental block, merely prompting participants to press a key. From the pilot study, participants are able to respond within three seconds. Based on this, a response within three seconds will be considered as proper engagement, and a participant that fails two or more of these checks will be excluded and replaced.

18.3. The task is structured so that one reward amount must always be accepted. Thus, a participant who quits every trial in at least one block will be assumed not to have followed or understood task instructions, or to have disengaged from the task altogether, and will be excluded and replaced.

18.4. In the cognitive effort condition, participants were forced to travel if they made 2 mistakes in a trial. Any participant with more than 30% forced travels will be excluded and replaced.