The influence of risk and value on affective decision-making in primates

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Introduction

○ Affective decision-making involves evaluation of the outcomes of options. Both the risk and value of outcomes affect behavior.

○ In humans and monkeys, the amount of variability in the outcomes of an option influences choice[2,4]. This variability has been quantified as the Coefficient of Variation (CV) and is a measure of risk[3,5].

○ Specifically, it has been found that adult humans avoid more variable options in favor of more consistent ones, while children and rhesus monkeys gravitate toward these risky options.

○ Although work thus far suggests that rhesus monkeys are generally risk-seeking, it is unclear whether this preference is truly dependent upon the risk and the value of the outcomes, especially regarding reward quality/likeability, independent of the specific task demands.

○ To test the extent to which rhesus monkeys are influenced by the risk and values of outcomes, we designed a food-based risky decision-making task, whereby the monkeys were given a choice between a certain medium payoff option and one that varied between no payoff and a high payoff.

○ Neural activity in areas such as posterior parietal and cingulate cortex have been found to correlate with risky decisions[3]. Less is known, however, about other brain areas such as the agranular/anterior insula and dorsolateral prefrontal cortex in similar risky paradigms. The insula, for example, has been shown to sensitize subjects to risk and value[1,6], making it a critical area to study.

○ To discern the neural role of these brain regions in risky decision-making, we next plan to record neuronal activity while the monkeys perform a fluid-based risky decision-making task .

Behavioral methods

SUBJECTS: *2 male rhesus monkeys (Macaca mulatta), monkey P and T.*
The monkeys' left arm was comfortably restrained to control for choice behavior

FOOD-BASED RISKY DECISION-MAKING TASK

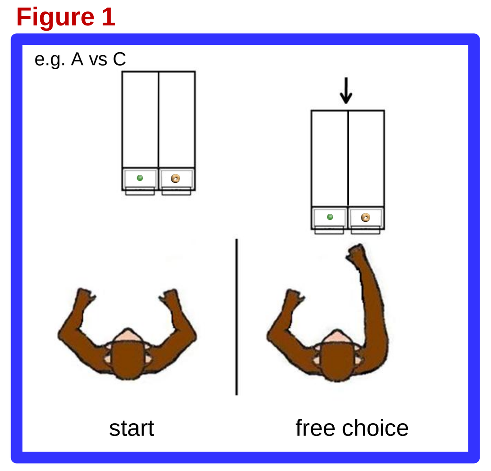
FOOD PREFERENCE PARADIGM

○ The monkeys were given a free binary choice between 2 of 3 different food items (A: mini M&M, B: mini marshmallow, and C: cheerio). The three conditions were A vs C, A vs B, and B vs C).

○ The 2 different food items were placed in transparent containers that were easily viewable to the monkeys. The experimenter then moved the apparatus forward and the monkeys lifted the container of his choice to grab the reward (see Figure 1).

○ Each condition was conducted for 60 trials per day (ITI 15 seconds) across 2 days per monkey. The locations of the food items was randomized every trial to control for side biasing.

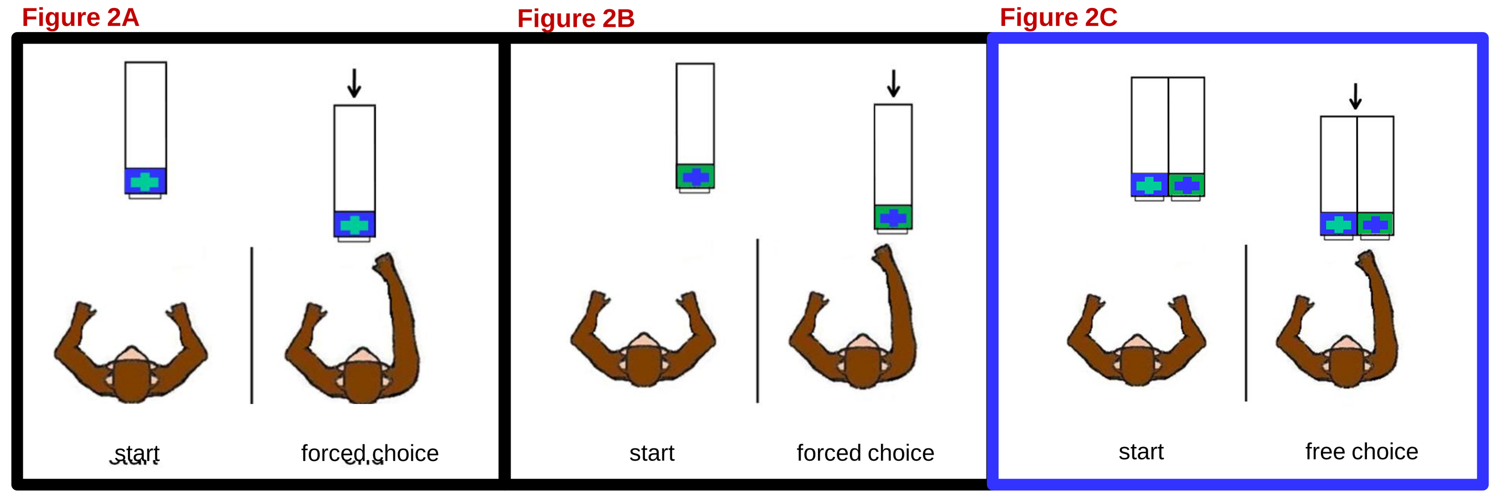
Figure 1



3 different food items (*A, B, C*)
Mini M&M (***A***)
Mini Marshmallow (***B***)
Cheerio (***C***)

RISK PREFERENCE PARADIGM

Figure 2A Figure 2B Figure 2C



○ Opaque lids (left side: green cross with blue background, right side: blue cross with green background) were used in this paradigm to prevent its contents from being seen by the monkeys (see Figure 2).

○ In each condition (see Table 1), the safe side always had one food item while the risky side had (a) a potential for a larger amount of the same food item but also (b) a possibility of no reward. In each condition, the monkeys made 4 forced choice trials on one side (Figure 2A), 4 forced trials on the other side (Figure 2B), and finally 8 free binary trials (Figure 2C). The initial side of the forced choice was randomly determined and the ITI between trials was 15 seconds.

○ This 4,4,8 trial design was repeated for 4 blocks a day and repeated for 3 days for a total of 12 blocks per monkey. To control for side biasing, the safe and risky option were then reversed, and 12 further blocks were run in the new configuration.

○ To examine stable preference, we analyzed only the last 30 free trials of each configuration (60 free trials).

○ The expected value/mean of an option is equal to the positive reward outcome multiplied by the probability of receiving it.

○ In Table 1, the Coefficient of Variation (CV) of an option was our operational definition of risk [3,5]. It is defined as (for the risky option): $\frac{\sqrt{(((x_1 - \text{mean})^2 + (x_2 - \text{mean})^2)/n)}}{\text{mean}}$

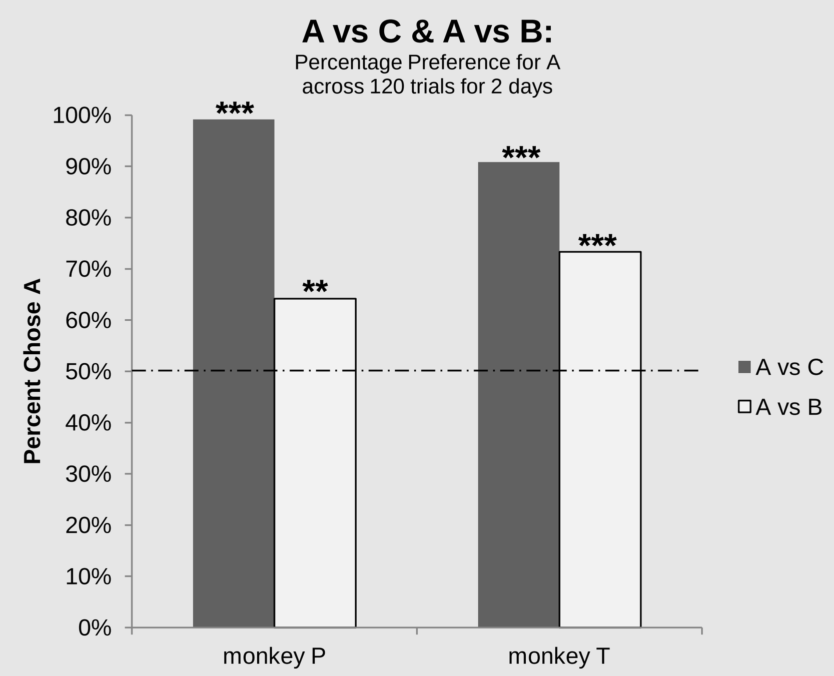
○ In the CV equation, x_1 and x_2 are the potential outcomes of an option, n is the number of outcomes, and the **mean** (or expected value) is calculated by multiplying the positive reward outcome by the probability of receiving it.

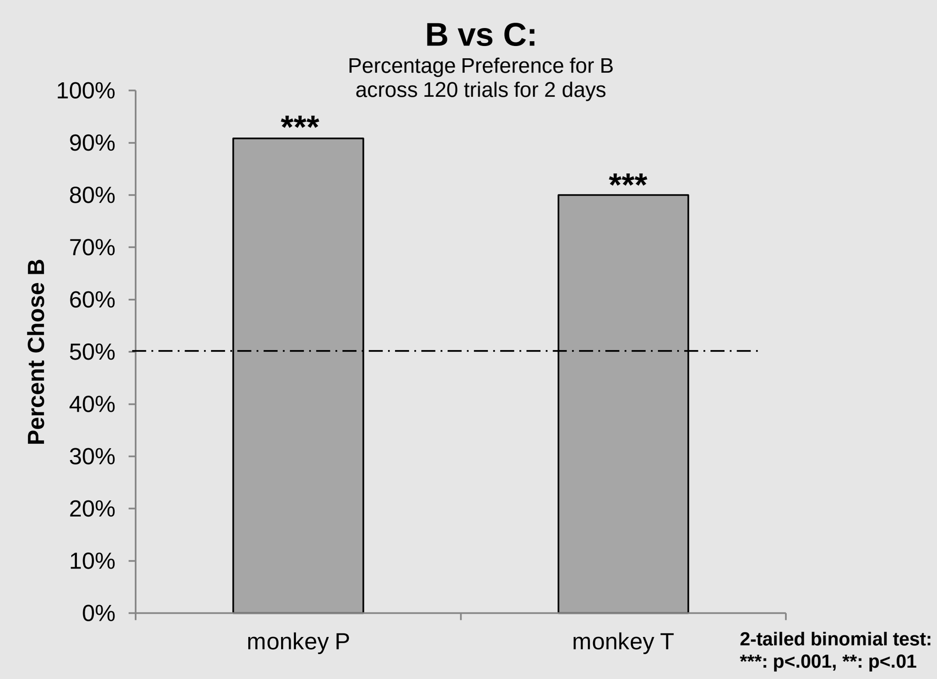
Table 1

CONDITION	Safe Option Outcome	Probability of Positive Outcome	CV (Risk) of Option	Expected Value/Mean of Safe Option	Risky Option Outcomes	Probability of Positive Outcome	CV (Risk) of Option	Expected Value/Mean of Risky Option
1	x1	100%	0	1	x2 / 0	50%	1	1
2	x1	100%	0	1	x2 / 0	50%	1	1
3	x1	100%	0	1	x4 / 0	25%	2.2	1
4	x1	100%	0	1	x2 / 0	50%	1	1
5	x1	100%	0	1	x8 / 0	12.5%	5	1
6	x1	100%	0	1	x2 / 0	50%	1	1
7	x1	100%	0	1	x2 / 0	12.5%	5	0.25

Behavioral Results

FOOD PREFERENCE PARADIGM



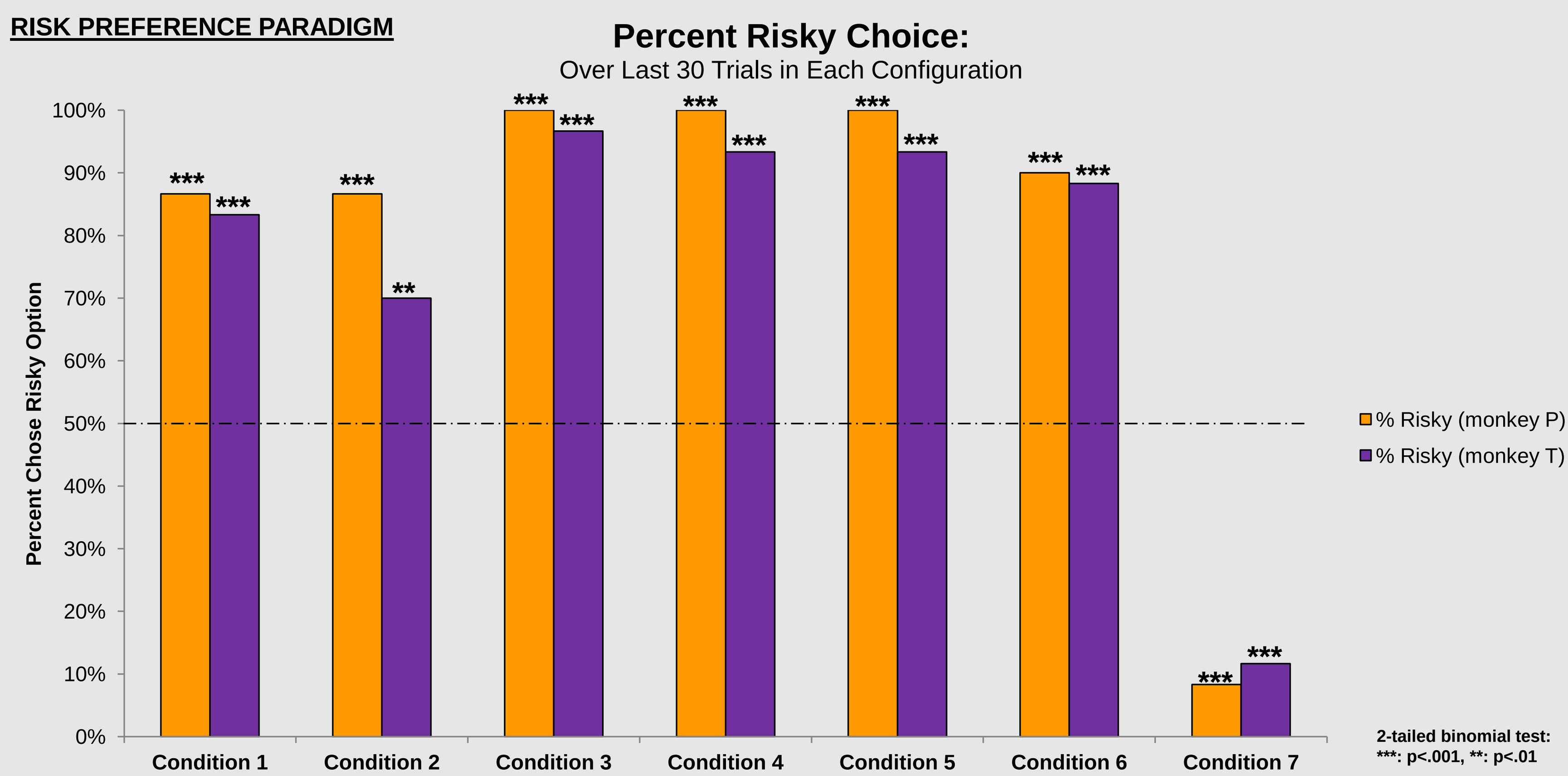


○ Both monkeys significantly preferred the mini M&M's over the cheerio (two-tailed binomial test; P: p< 0.0001, T: p< 0.0001) as well as the mini marshmallows (two-tailed binomial test; P: p= 0.002, T: p< 0.0001). The monkeys also preferred the mini marshmallows over the cheerios.

○ Thus, the subjective value/likeability of the food items was ranked as follows for both monkeys:

mini M&M (A) > mini marshmallow (B) > cheerio (C)

RISK PREFERENCE PARADIGM



○ Both monkeys significantly preferred the risky option across all conditions when the expected value/mean of the safe and risky options were the same (**Conditions 1-6**).

○ Both monkeys significantly preferred the safe option when the expected value/mean of the safe option was higher than the risky option (**Condition 7**).

○ Both monkeys significantly preferred the risky option despite changes in reward quality/likeability (**Condition 1, 2, 4, and 6**)

Neurophysiology Methods

SUBJECTS: *2 male rhesus monkeys (Macaca mulatta), monkey P and T.*
The monkeys' head was fixed and an eyetracker (Arrington Research, Inc. Scottsdale, AZ) was used to record eye position

FLUID-BASED RISKY DECISION-MAKING TASK

○ As shown in Figure 3, each trial begins when a fixation point, a small white circle, appears at the center of a video screen along with one (Figure 3A, 3B) or two saccade targets (Figure 3C). Once the monkey fixates the circle, it turns green. The monkey then must maintain central fixation for 500 ms, after which the fixation point disappears. This event serves as a "go" cue for the monkey to make a saccadic eye movement to a target.

○ Upon successful completion of all steps, the monkey receives a number of squirts of the fluid reward according to the experimental contingency (described below).

○ To deliver the different squirts of fluid rewards we use the Mitz pressure reward system (*Crist Instrument, Hagerstown, MD*).

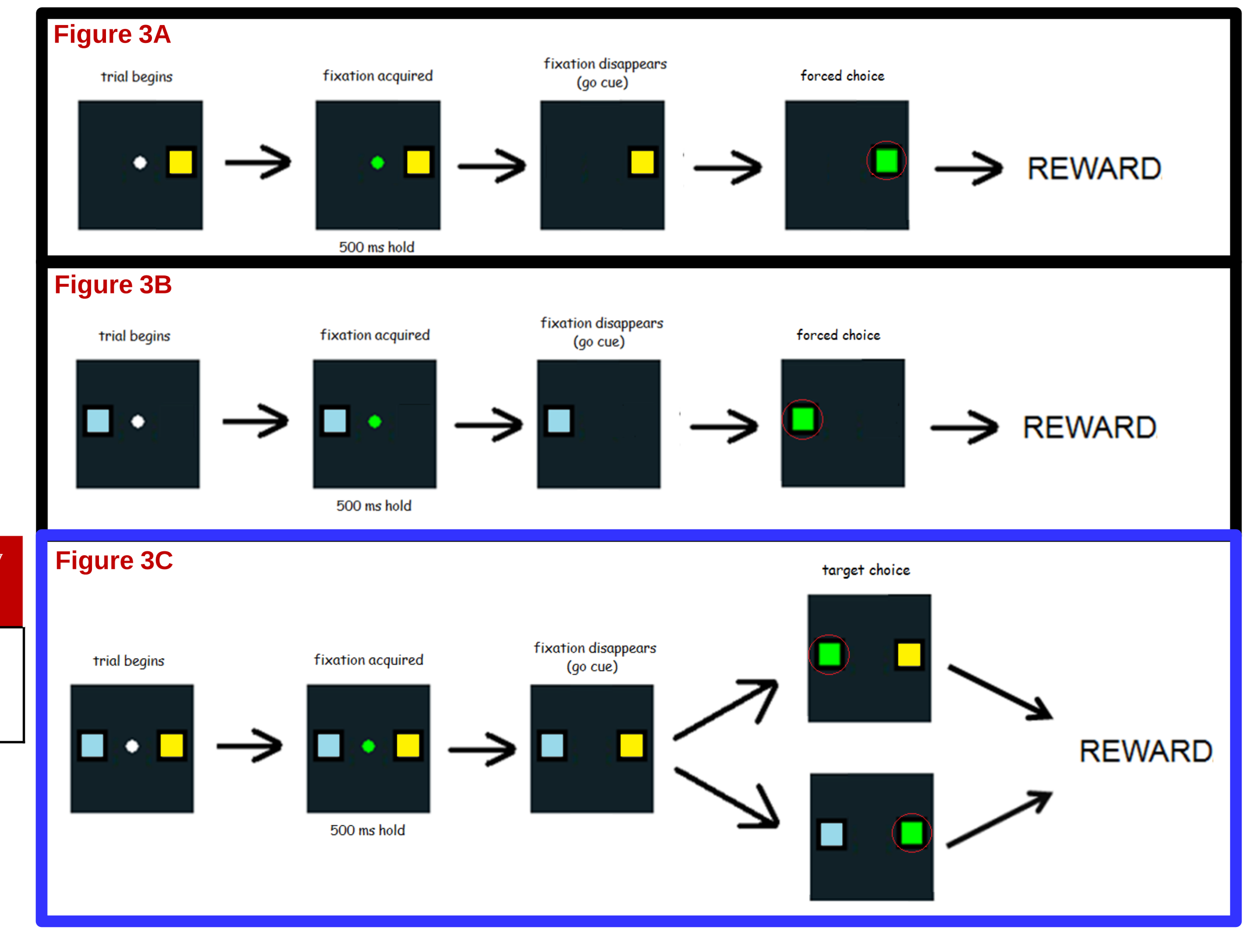
○ In our equal expected value condition (see Table 2), the safe target always gives 3 squirts of juice, whereas the risky target gives a 50% chance of 5 squirts of juice and a 50% chance of1 squirt of juice.

○ In each condition, the monkeys made 4 forced choice trials on one side (Figure 3A), 4 forced trials on the other side (Figure 3B), and finally 2 free binary trials to either side (Figure 3C). This 4,4, 2 block structure was used to enhance learning. The initial side of the forced choice was randomly determined for each block.

Table 2

Safe Option Outcome	Probability Positive Outcome	CV of Safe Option	Risky Option Outcomes	Probability of Outcomes	CV of Risky
x3	100%	0	x5 / x1	50% / 50%	0.67

Figure 3A Figure 3B Figure 3C



Preliminary Neurophysiology Results

○ While monkey T performed the fluid-based risky decision-making task, we are using a multi-electrode and recording system (*Plexon, Inc., Dallas, TX*) to record single neurons from the dorsolateral prefrontal cortex.

○ Figure 4 shows a *dorsolateral prefrontal* cortex neuron raster (top) and histogram (bottom). The neuron fired significantly more (p=0.0118) prior to safe choices compared to risky choices for both configurations, and was not significantly tuned for movement location (p=0.2891)

PERIODS OF ANALYSIS:

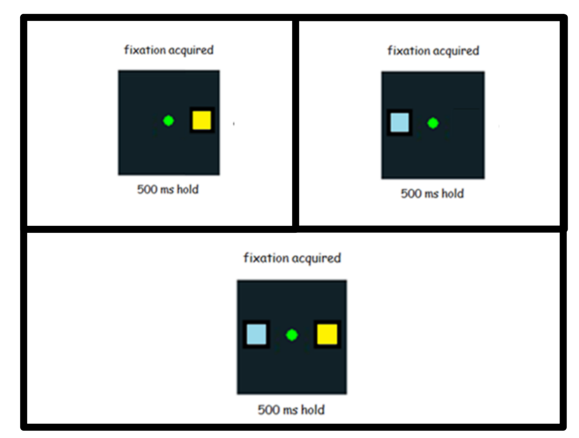
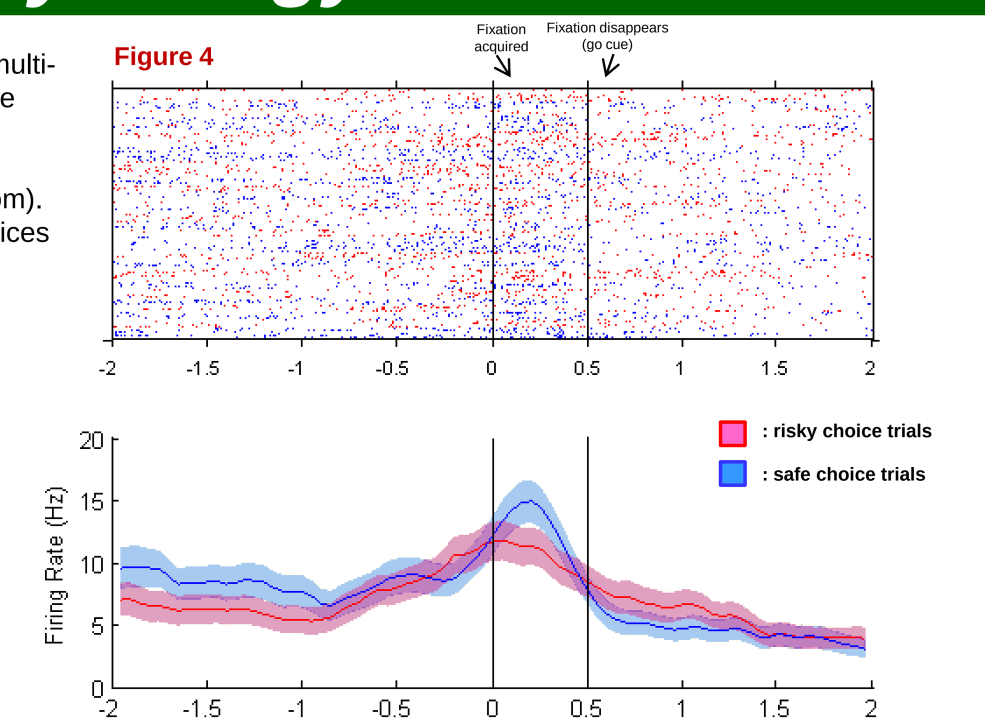


Figure 4



Conclusions and future directions

○ In a food-based risky decision-making task, our monkeys (P and T) preferred the risky option under all conditions of risk, independent of the likeability of the reward. These results suggest that rhesus monkeys may be highly fixated on the larger potential positive reward, which is suggested by our computational analyses of the data. Our monkeys, however, preferred the safe option when its overall expected value was higher than the risky option. This suggests that zero outcomes affected the monkeys' behavior and that they were not solely driven toward the highest potential reward.

○ In a fluid-based risky decision-making task, preliminary neural data from the *dorsolateral prefrontal cortex* showed a neuron whose activity preceding choice was higher for *safe* choices than for risky ones.

○ We plan to continue recording neurons in the dorsolateral prefrontal cortex as well as from the agranular/anterior insula in both monkeys as they perform the fluid-based risky decision-making task across different conditions of risk and value. We also plan to microstimulate these regions to determine their potential causal role in risky choice behavior. Finally, we also plan to computationally model both the behavioral and neuronal findings to gain further insight into risky decision-making and the underlying neural dynamics.

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