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PROJECT REPORT

"Suboptimal decision-making due to stress and anxiety in sequential foraging tasks"

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Abstract

Neuro-ethological decision-making refers to the decision-making involved in natural behavioral tasks done by animals in their day-to-day life.
Foraging behavior is one such ethological paradigm useful in understanding various behavioral mechanisms such as motivation, risk aversion, defense mechanisms, and the ability to make a tradeoff between exploration and exploitation. A patch foraging task models foraging behavior through the explore-exploit tradeoff. We hypothesize that in the case of trait anxiety, state anxiety, and depression, there would be specific kinds of suboptimal behavior observed in the task.
In this SURGE project, we aim to study foraging behavior by designing a naturalistic patch foraging task and analyzing the data collected using suitable mathematical models to test whether stress and anxiety affect decision-making.

Introduction

Why neuroethological decision-making?

Unlike other kinds of decision-making such as that involved in gambling tasks, multiple-armed bandit tasks, etc., neuroethological decision-making involves scenarios that are encountered in real life that allow for a better understanding of the behavioral changes caused due to stress.

Foraging behavior

Foraging is a neuroethological paradigm that is said to have a huge impact on the evolution of decision-making. It involves making a tradeoff between exploration and exploitation in order to optimize the outcome. Foraging has been studied extensively to understand the correlation between decision-making and behavioral changes caused due to stress. A patch foraging task models foraging behavior in humans and other species by deciding whether to forage at the current patch or to move to another patch in hopes of getting a greater reward.

Correlation between stress and neuroethological decision making

Mental health conditions such as general anxiety disorder and depression that manifest as a result of continual stress interfere with decision-making. Foraging behavior would help us in understanding this correlation.

We hypothesized that overexploitation can be associated with trait anxiety, while early leaving of the patch can be associated with state anxiety. In the case of depression, participants tend to make more exploratory decisions.

Objective

1. Design a naturalistic sequential patch foraging task
2. Investigate the sub-optimality in foraging behavior under high stress and anxiety levels
3. Assess the stress levels and behavioral changes caused by the COVID pandemic
4. Refine the foraging game design to allow for better analysis in the context of stress and anxiety
5. Couple the foraging task with the EEG and pupillometry for further analysis

Literature review

Foraging behavior

Animals are in some way optimizing their foraging activities. In a patchy environment, food is found in clumps or patches and the forager (an animal or a human) must stay in the patch and collect food items before deciding to move to another patch for food. Moving to another patch would cost energy and time and hence, the forager must optimize the time they spend in the patch and when to leave the patch. They must also make decisions as to which patch types to visit by taking into account various factors such as the risk of encountering a predator, finding a mate, etc.

In this context, we discuss the former i.e., deciding when to leave a particular patch. Since staying in a patch means food from the patch is being consumed. It is assumed that spending more time in the patch depletes the patch (the patch becomes less rewarding) and consequently the food intake also goes down. Hence, the curve for the amount of reward obtained for time t spent on the patch would look like the one in Fig.1, ignoring other factors such as the risk of encountering predators, etc. Here, Patch Type 1 is a rich environment and Patch Type 2 is a poor environment since they are more and less rewarding with respect to the time spent in the patch respectively.

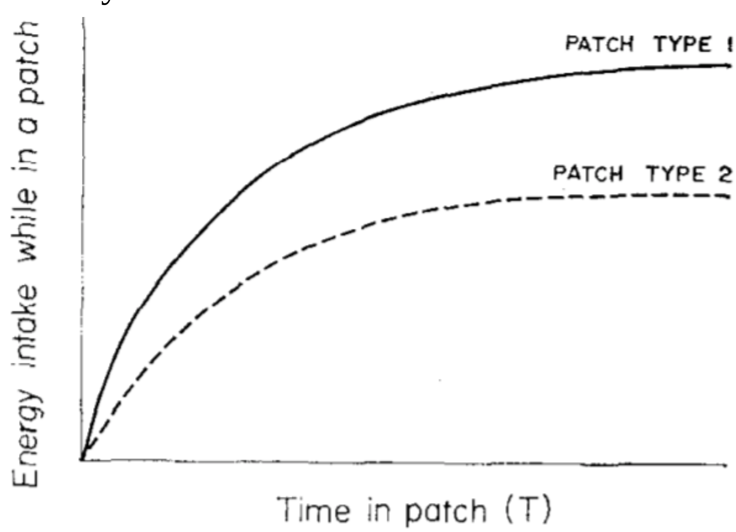

Fig 1. Marginal Value curve for Energy obtained vs Time spent in the patch (ref, Charnov, 1974)

The Marginal Value Theorem

The Marginal Value Theorem dictates the optimal strategy for patch foraging.

In a foraging environment with temporally decaying resources, subjects must move from one patch to another to maintain a continuous amount of reward value. The task here is to make the decision between staying in a patch i.e. exploit the patch or moving to a new patch i.e. exploring new patches. Each patch contains a certain amount of reward which decays with time. So after a certain time, the subject should opt between continuing to forage at the same patch or to leave for a new patch. Traveling time doesn't add any reward value.
Optimality of foraging is maintained if the forager follows the Marginal Value Theorem in the context of the explore/exploit trade-off and the energy cost to get the reward which helps unveil the complex decision procedure. The marginal value theorem dictates that the forager must leave the patch when the reward drops below the marginal reward rate from the patch. Later it was found that the MVT also has constraints that results in a leaving time slightly below the optimal leaving time (Campbell et al., 2020).

Suboptimality under stress

When under chronic stress, participants deviate from optimal behavior
State Anxiety: Early leaving of the patch leading to lower reward collection at each patch
Trait Anxiety: Overexploitation of current patch and fewer exploratory decisions
Depression: More exploratory decisions (risk-seeking) and fewer exploitatory decisions
COVID stress: Several recent studies discuss how the COVID pandemic has been acting as a natural, chronic stressor in many cases. COVID stress manifests as anxiety disorder, depression, and/or PTSD

Neural correlates

It has been found that during a foraging task, neural activity remains remarkably consistent. Activity is observed in the dorsal anterior cingulate cortex (dACC) and in regions homologous to the dACC in rodents and primates (Pearson et al., 2014)
Various explore-exploit tradeoff-based tasks showed that primates always try to maximize their gain following the Marginal Value Theorem i.e., they continue to forage in a patch until the threshold where reward dipped below mean value. During this behavior, the choice computation and exploit to explore transition

were clearly visible from a single neuron level recording in the ACC region. This neuron showed an increase in firing with the rate of decaying reward and the firing reached a maximum when the individual generated an explore decision i.e. to leave for a new patch. This is hypothesized as the neural threshold of patch leaving.
ACC firing took place specifically in a burst when the decision was made and not during the whole task duration, relating it specifically to the choice behavior.
Another important finding regarding foraging decisions is that the neural circuit and the neuromodulators act in conjunction, where the neural circuit controls the action pattern while the neuromodulators regulate shift circuits from one stable pattern to another (correlated with patch change).
Further, it was found that the neurotransmitter dopamine also plays an important role in dynamic decision-making involved in foraging tasks (Campbell et al., 2020).

Timeline:

1. Reviewing several papers for designing the game
2. Understanding the working of the software by implementing some simple tasks
3. Designing the basic game using PyschoPy Builder
4. Revamping the foraging game by designing it in pure python using various packages such as psychopy, NumPy, etc. with a few modifications from the previous design
5. Surveying participants with the questionnaire and the foraging game
6. Analyzing the data collected

Game design:

The game was designed using PsychoPy (a python package for behavioral science experiments). The game consists of a sequential patch-foraging task with two environments. In each environment, the player is presented with a screen that displays three clickable stimuli, the circular box in the center, the tree (patch) to the right (or left) of the circular box, and the square box with a forward arrow on the other side of the circular box. To make a decision, the player must click the circular box in the center, wait for it to turn green (one second wait time), and either click on the tree or the square box with the forward arrow. Clicking on the tree would result in a reward, displayed for 0.5 seconds, after which the player can do the next trial. Hence the harvest time is approximately 2 seconds (equal to the sum of the wait time and the reaction time (the time it takes to move from the center to the patch) + 0.5 sec). Clicking on the square box with the forward arrow would result in moving to the next tree, in the front. If in the next trial the player chooses not to move forward and stay at the same tree, they would receive a reward lesser than what they previously received at the tree (indicating a depletion of the reward from the tree).

The distance of the next tree from the current tree is dependent on the environment. In the first environment, it takes 4 seconds to reach the next tree when the subject decides to leave the current patch, while in the second environment, this travel time is equal to 8 seconds. In both environments, the speed of the screen is the same and equal to 67.5 pixels per second. The trees appear in an alternating fashion to the left or right of the circular box in the center.

In each environment, the player spends 120 seconds(2 minutes) and the goal of the player is to maximize the reward collected by deciding when to leave the current patch/tree and move to the next.

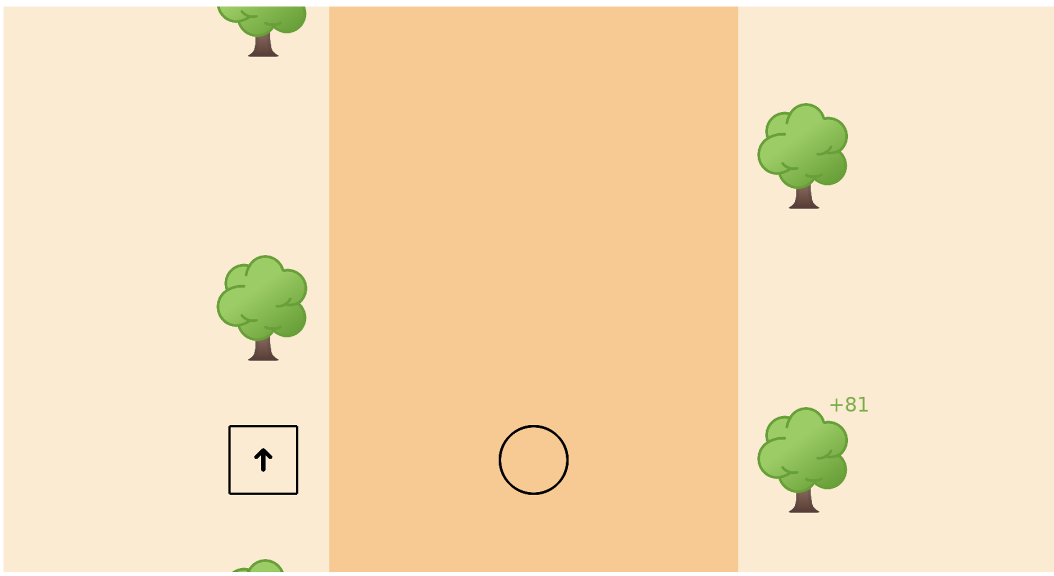

Fig 2. The spatial design of the first environment (travel time = 4s) of the foraging task.

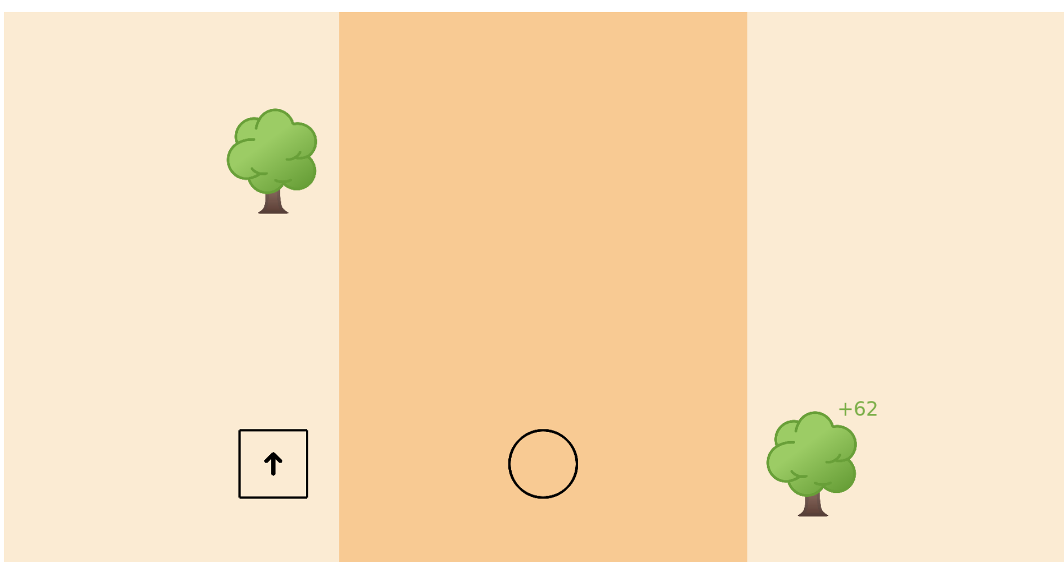

Fig 3. The spatial design of the second environment (travel time = 8s) of the foraging task.

Reward function:
What amount of berries/reward the forager receives after foraging a given patch is dictated by a built-in reward function. It is a linear function with a variation of 10 units (berries/reward value) about the mean, i.e., in the first trial ($i = 1$), the reward is a random value between 100 and 85 (for uniformity), and for the i^{th} trial ($i > 1$, $i \leq 10$)

$$reward_i = a\ random\ value\ between\ sval_i\ and\ eval_i$$

where

$$eval_i = 10 * (10 - i) + 5$$
$$sval_i = 10 * (9 - i) + 5$$

After the 10^{th} trial, the function would result in a reward of zero berries.

Parameters recorded in each environment:
1. Tree number: Indicates the n^{th} tree encountered in the environment.
2. Time elapsed: Time from the start of the game to the time when the decision (click) is made.
3. Decision made: Stay/harvest or leave depending on the mouse click.
4. Reaction time: Time between the click on the center to the click on either the tree or the forward arrow.
5. Reward: number of berries collected in that trial.

Survey

The survey consists of a self-assessment questionnaire designed from the various standard questionnaires. The sections were the following:
Section 1: General information
Section 2: PHQ-9
Section 3: GAD-7
Section 4: STAI Part 1
Section 5: STAI Part 2
Section 6: COVID related questions

Participants:

The data of a total of 20 participants between the age of 17 and 31 were collected out of which 14 were male and 6 were female. The participants were asked to fill the survey right before playing the foraging game. Some participants reported the data collected on their second trial while the others reported the data from the first trial. This lead to considerable variability in the data.

Data analysis:

A. Calculation of optimal leaving time from a patch using Marginal Value Theorem:

The Marginal Value Theorem provides a normative account of how an animal should forage in an environment where rewards are accumulated in patches. According to the Marginal Value Theorem, the forager should leave the patch they are presently in when the marginal reward rate in the patch ($\frac{\partial g(T)}{\partial T}$) drops to the average reward rate for the environment (Charnov, 1974). Hence, the equation for foraging optimally in an environment, ignoring other factors such as risk, becomes:

$$\frac{\partial g(T)}{\partial T} = E^* = \frac{\partial h(T)}{\partial T} = \frac{h(T_0)}{t + T_0}$$

where *T* is the time spent by the forager in a given patch, *t* is the time it takes to travel between two patches, *h(T)* is the reward collected after spending *T* time units in a given patch, *g(T)* is the reward available after correcting for the cost of searching for rewards in a given patch and *E** is the optimal rate of reward collection in the environment when the forager spends T_0 time in all the patches given every patch is almost similar in our foraging task.

Given that the cost of searching for rewards in a given patch is zero(since there was no decrement or deduction in the rewards collected as the subject foraged through the patch, *g(T) = h(T).*

Patch leaving time was used as the dependent variable for analysis, as this was the primary behavioral measure from the task.

Substituting the values of the travel times (4 and 8 seconds) for both the environments and approximating the reaction time to be 2s (see Fig below), the slope of the linear fit for the graph came to be -5.064 with an intercept of 100.929. On applying the Marginal Value Theorem, the optimal leaving time was found to be 11.9653 seconds (approx. 12) and 13.9653 seconds (approx. 14).

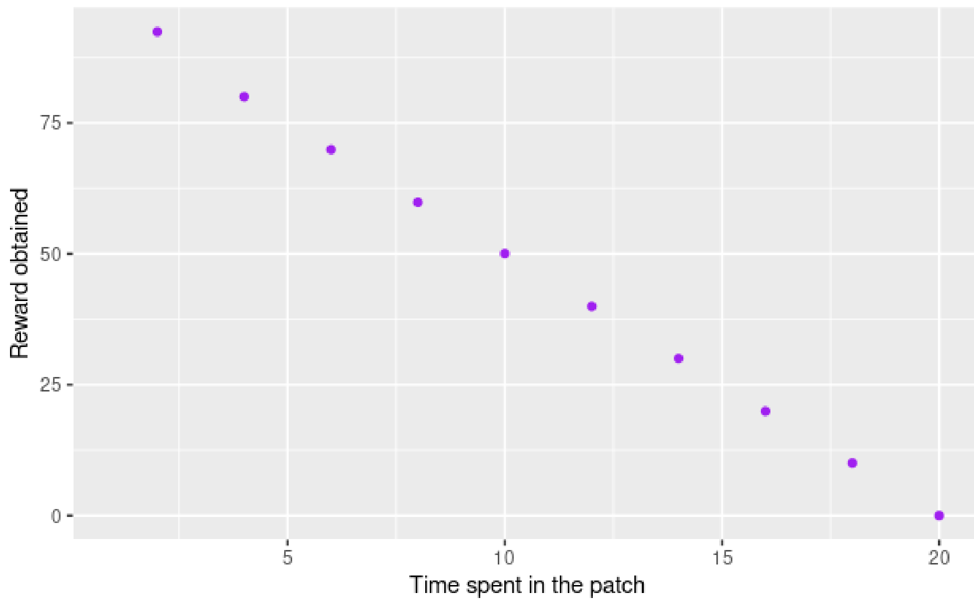

Fig 4. The plot of average reward/berries vs time spent (in sec) in the patch

B. T-test for average leaving times for all the participants in the rich and poor environments:

The t-test (see Fig below) was done by plotting the average leaving times of 14 participants in the rich (travel time of 4 seconds) and the poor environment (travel time of 8 seconds) respectively. Considerable variability is observed in the leaving times but on average, the leaving time for these participants was found to be higher in the case of the poor environment (12.9670 seconds in the rich environment and 14.0430 seconds in the poor environment). This is what is expected as the participants must spend more time foraging at the same patch in a sparse environment.

However, in the remaining participants, this result did not hold true possibly because of the lack of familiarity with the first environment while giving the first trial.

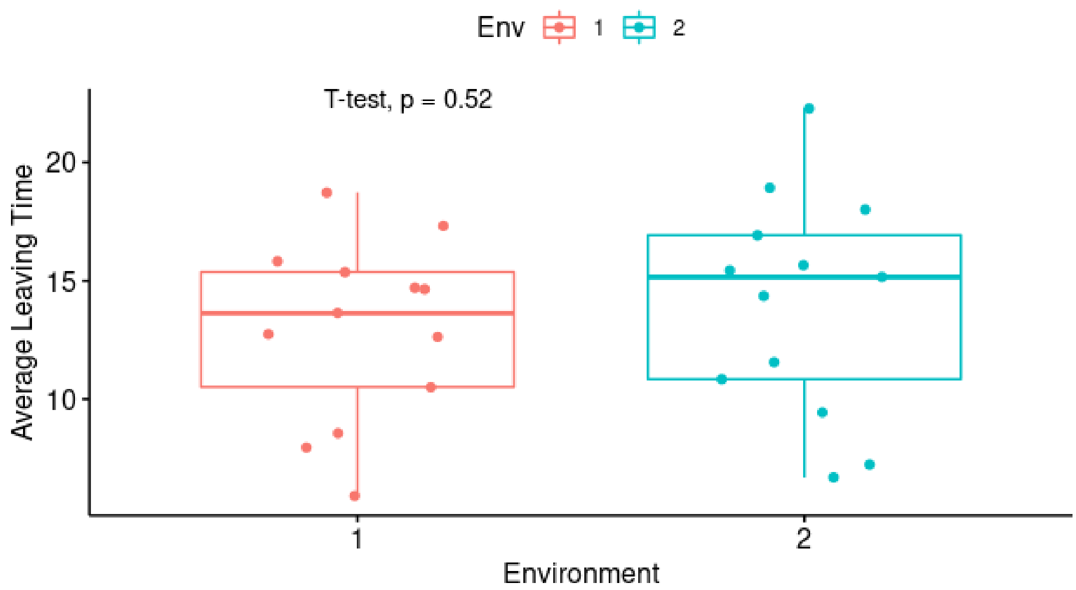

Fig 5. The t-test for leaving times (in sec) in rich (Environment 1) vs poor (Environment 2) environments.

As can be seen from the above analysis, we observe that the participants deviate slightly from optimal behavior (given by MVT) by overstaying in the patches (for approximately 1 second in each environment). This is concurrent with the result obtained in Campbell et al., 2020.

Future work:

Further, we plan on working on the following aspects to complete the study:

1. Analyze the survey responses to assess stress levels in the individuals
2. Analyze the game data further using Reinforcement learning techniques
3. Rectify the errors in the game design in order to design a fully functional game
4. Couple the final game with EEG and pupillometry for future research

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