Choice Coding in Frontal Cortex during Stimulus-Guided or Action-Guided Decision-Making

PRESENTATION

Aryan Dhawan
2021023

Kunal Sharma
2021331

Sarvagya Kaushik
2021350

Vansh
2021363

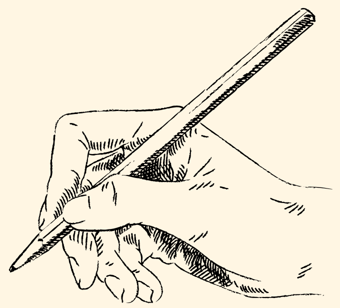
INTRODUCTION

- Daily Choices:
  - Based on perception and actions.
  - Brain predicts outcomes from:
    - External Stimuli: Environmental cues.
    - Internal Actions: Movements/decisions.
- Key Brain Regions:
  - Orbitofrontal Cortex (OFC):
    - Links external cues to rewards.
    - Supports decisions based on sensory inputs.
  - Anterior Cingulate Cortex (ACC):
    - Connects actions to outcomes.
    - Helps in decision-making based on actions.

INTRODUCTION

- Why This Matters:
  - Understanding OFC and ACC functions offers insights into behaviors and decision-making disorders.
- Key Questions:
  - Are OFC and ACC specialized for different decision types?
    - OFC: Active in Stimulus–Outcome (SO) decisions?
    - ACC: Active in Action–Outcome (AO) decisions?
- Aim of the Study:
  - Investigate how OFC and ACC neurons handle SO and AO tasks.
  - Examine roles of individual neurons during decision-making.
- Contextual Basis:
  - Previous research linked OFC to SO and ACC to AO, but neuron-level details remain unclear.
  - This study aims to address this gap.

KEY HYPOTHESES



- Primary Hypothesis:
  - ACC and OFC exhibit distinct roles in decision-making:
    - OFC: Encodes choices via Stimulus–Outcome (SO) associations.
    - ACC: Encodes choices via Action–Outcome (AO) associations.
- Research Goals:
  a. Single-Neuron Encoding:
     - Examine if ACC and OFC neurons differently encode choices in SO vs. AO tasks.

  b. Neuronal Specificity:
     - Analyze how neurons in ACC and OFC predict stimuli or actions and outcomes in task-specific contexts.

  c. Functional Division:
     - Validate dissociation:
       - OFC: Stimulus-based decisions.
       - ACC: Action-based decisions.

METHODOLOGY

- Subjects:
  - Two male rhesus monkeys trained to perform specific decision-making tasks.
- Tasks Overview:
  - Designed to explore how decisions are made based on either external stimuli (what we see) or actions (what we do).
- Two Key Tasks:
  - Stimulus–Outcome (SO) Task:
    - Sampling Phase: Monkeys saw two pictures, each linked to a juice reward.
    - Choice Phase: They chose the picture associated with their preferred juice by moving a lever.
  - Action–Outcome (AO) Task:
    - Sampling Phase: Monkeys performed two actions, each linked to a juice reward.
    - Choice Phase: They repeated the action linked to their preferred juice.
- Purpose:
  - To observe how different brain regions process decisions based on what monkeys see (stimuli) versus what they do (actions).

METHODOLOGY

- Neuronal Recording:
  - ACC (Anterior Cingulate Cortex): Focuses on actions and their outcomes.
  - OFC (Orbitofrontal Cortex): Focuses on stimuli and their outcomes.
  - Neural activity recorded using electrodes during the sampling and choice phases to identify how these regions respond.
- Task Phases:
  a. Sampling Phase: Monkeys experience predictive events:
     - SO Task: Pictures followed by juice rewards.
     - AO Task: Actions followed by juice rewards.

  b. Choice Phase: Monkeys select either a picture (SO) or an action (AO) for a better reward.
- Rewards:
  - Three Types: Preferred juice, less preferred juice, and bitter juice (quinine).
  - Designed to motivate clear preferences in decisions.

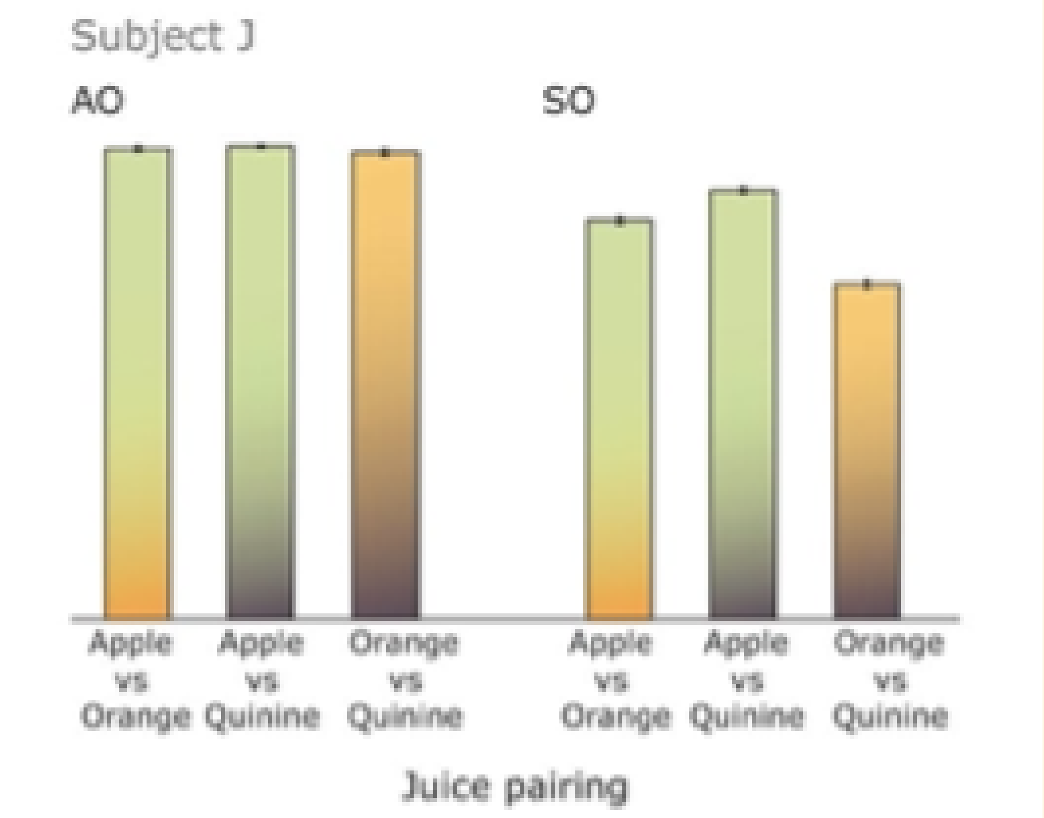
METHODOLOGY

- Behavioral Performance:
  - Monkeys' choices were measured by the percentage of trials where they selected the preferred juice.
  - Reaction Times:
    - Faster in AO tasks, suggesting actions might be easier to process than stimuli for decision-making.
- Data Analysis:
  - Spike Density Histograms:
    - Used to visualize brain activity during tasks.
  - Statistical Tests:
    - Sliding two-way ANOVA examined how neurons respond to stimuli or actions and the rewards they predict.
  - Outcome Encoding:
    - Assessed the strength and timing of neural signals related to predicting outcomes.

KEY RESULTS

- Behavioral Preferences:
  - Monkeys selected their preferred juice (apple/orange) in 88% of trials, demonstrating a clear understanding of the tasks as it can be seen in Graphs 1&2.
  - Successfully used both stimuli and actions to make their choices.
- Reaction Times:
  - AO Task (Action–Outcome): Faster (199-266 ms).
  - SO Task (Stimulus–Outcome): Slower (709-744 ms).
- Interpretation:
  - Faster reactions in the AO task suggest that action-based decisions involve more straightforward planning.
  - Stimulus-based decisions require active selection, making them slower.

Graph 1 | Chosen Juice vs Offered Juice Pairs by Subject H



Graph 2 | Chosen Juice vs Offered Juice Pairs by Subject J

KEY RESULTS

Neuronal Encoding in ACC and OFC (Sampling Phase):

- Outcome Encoding:
  - Both ACC and OFC neurons encode outcome information, but with task-specific strengths:
    - OFC: Stronger encoding in SO tasks (stimulus-based decisions).
    - ACC: Stronger encoding in AO tasks (action-based decisions).
- Interpretation:
  - The difference between the encoding neurons during AO task in ACC and SO task in OFC is not statistically significant. Hence the study outcome is consistent with the hypothesis but still weak.
  - Supports the hypothesis of task-specific encoding:
    - OFC: Specialized for stimulus-outcome (SO) associations.
    - ACC: Specialized for action-outcome (AO) associations.

Table 1. Percentage of recorded neurons with significant encoding of the predictive event or the outcome it predicted at any point from the delivery of the first outcome until the end of the first delay

Selectivity	Area	Predictor	Outcome	Predictor × Outcome
AO only	OFC	**12**	**17**	6
	ACC	**12**	**11**	**11**
SO only	OFC	6	**18**	**8**
	ACC	6	**19**	5
Both	OFC	1	**14**	1
	ACC	2	**17**	0

Table 1 | *Bold means statistically significantly higher than expected number of neurons

KEY RESULTS

Action Encoding During the Choice Phase:

- Action Selectivity:
  - Neurons in both regions encoded the chosen action, but strengths differed by task:
    - ACC: Higher encoding in AO tasks (actions-based decisions).
    - OFC: Higher encoding in SO tasks (stimulus-based decisions).
- Interpretation of Findings:
  - We see robust encoding of the action necessary to make the choice.
  - Encoding of this action was more prevalent in OFC in the SO task and more prevalent in ACC in the AO task.
  - The results suggest that the function of the two areas is not so much the encoding of specific AO or SO associations per se, but rather using those associations to guide choice.

Table 2. Percentage of recorded neurons with significant encoding of Stimulus (left/right position of the pictures), Action (the animal's choice: left or right) or Outcome (the type of juice associated with the choice) during the delivery of the second reward up until the time of the chosen action (based on the subject's median reaction time for each task)

Selectivity	Area	AO task	SO task
Stimulus	OFC	—	1
	ACC	—	0
Action	OFC	**10***	**20***
	ACC	**16***	**10***
Outcome	OFC	**9**	7
	ACC	**10**	6
S × A	OFC	—	**12**
	ACC	—	**18**
S × O	OFC	—	2
	ACC	—	4
A × O	OFC	3	5
	ACC	5	7
S × A × O	OFC	—	**8**
	ACC	—	**10**

Table 2 | *Bold means statistically significantly higher than expected number of neurons

Research LIMITATIONS

01 Limited Neuronal Encoding of AO and SO Associations

The study observed limited neuronal encoding of AO and SO associations, with only a small population of neurons specifically encoding these associations. This finding suggests that other brain regions, such as the amygdala for SO associations or motor areas and the striatum for AO associations, may be primarily responsible for storing these associations.

02 Task Design Constraints

The task design focused on working memory and "online" decision-making processes, which may have restricted the ability to detect a clear dissociation between OFC and ACC in terms of long-term associative encoding. This constraint could have influenced the observed patterns of neuronal activity.

03 Influence of Task Mechanisms

The design of the SO task precluded the use of Pavlovian responses, potentially biasing the observation of action encoding in OFC. Furthermore, the specific type of response required from the subjects, such as lever movements versus eye movements, likely played a significant role in shaping the observed neuronal encoding patterns.

THANKS FOR WATCHING

If you have any questions, let us know!