INVESTIGATING BELIEF UPDATING AND REWARD PROCESSING IN SCHIZOPHRENIA

A Comparative Analysis of Cognitive Tasks

Research Context & Key Questions

Schizophrenia and schizoaffective disorders significantly impact cognitive flexibility and decision-making processes, affecting patients' ability to: Integrate new sensory information with prior knowledge, Utilize working memory effectively, Process rewards appropriately to drive learning

Our research investigates:

1. How belief updating mechanisms differ in schizophrenia
2. Whether traditional assessment paradigms capture real-world decision-making complexities
3. If our novel Tree-based task provides more ecologically valid measurement of integrated cognitive processes

1 Introduction

1.1 The Beads Task

The Beads Task assesses probabilistic reasoning by asking participants to determine which of two jars containing different colored bead ratios (85:15 and 60:40) is the source of a presented sequence. The key measure, Draws to Decision (DTD), quantifies evidence gathering before judgment, with lower scores indicating a "jumping to conclusions" bias commonly observed in schizophrenia.

1.1.1 Design and Procedure

The Beads Task consisted of two rounds with different jar configurations. In the first round, one jar contained 85% beads of color A and 15% of color B, while the second jar had the reverse ratio. The second round used a more ambiguous 60%/40% distribution. Each round comprised 10 trials. On each trial, participants were shown a bead ostensibly drawn from one of the jars and asked to rate their confidence (0-100) regarding which jar was being used. Participants could either decide on a jar or request another bead. This process continued until the participant made a final jar decision, at which point they provided a final confidence rating. The task measured both the number of beads requested before decision (DTD) and the evolution of confidence ratings throughout the evidence accumulation process.

1.2 The Probabilistic Learning Task

This task examines reward processing under uncertainty by having participants choose between two stimuli with different reward probabilities (80-20 and 50-50). It measures choice behavior, reaction times, and learning curves while neural markers (RewP and P300) capture the underlying reward evaluation processes that may be altered in schizophrenia and depression.

1.2.1 Design and Procedure

Participants completed a three-block Probabilistic Reward Learning (PRL) task to assess feedback-based learning and decision-making. After a 20-trial practice block, they completed two 60-trial experimental blocks. In Block 2 (80/20), one shape had an 80% reward probability (+0.50 points), and the other 20% (0.25 points). In Block 3 (50/50), both shapes had equal 50% reward/punishment probability. Shape-reward mapping and left-right positions were counterbalanced. Participants selected shapes using "F" (left) or "J" (right) within 1000 ms; late responses received no feedback. Reward probabilities were undisclosed, encouraging learning through trial and error.

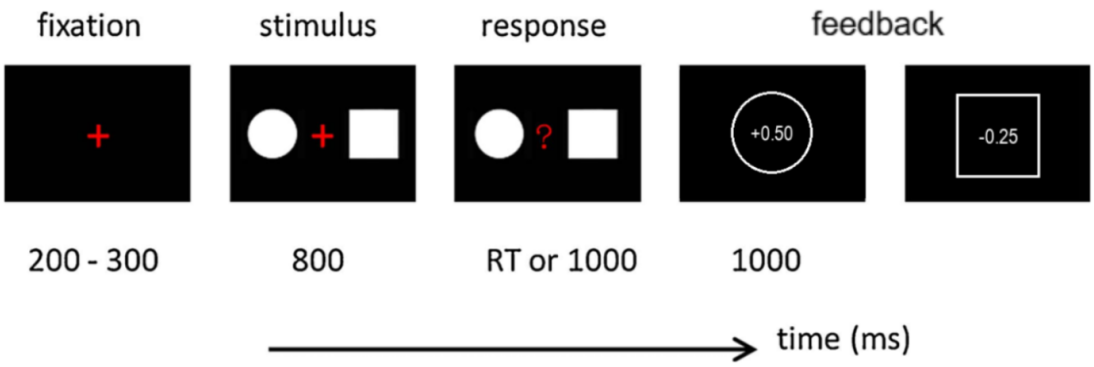


Fig. 1. Schematic illustration of the task design.

1.3 The Tree Task (Foraging Game)

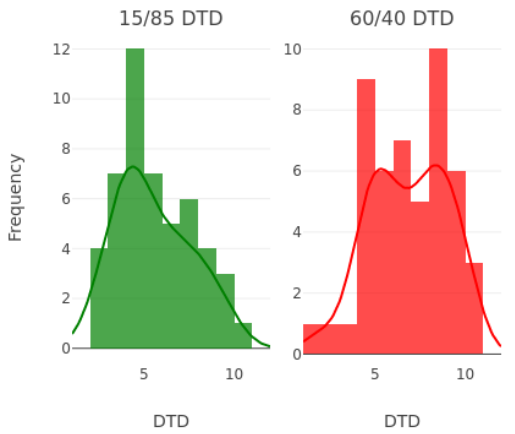
The Tree Task is a novel ecological paradigm where participants select from "trees" with shifting reward patterns. Unlike traditional isolated-process assessments, it simultaneously evaluates belief updating, reward sensitivity, and working memory in an integrated approach that mimics real-world decision-making complexity, potentially offering greater ecological validity for understanding cognitive flexibility deficits in schizophrenia.

2 Experimental Results

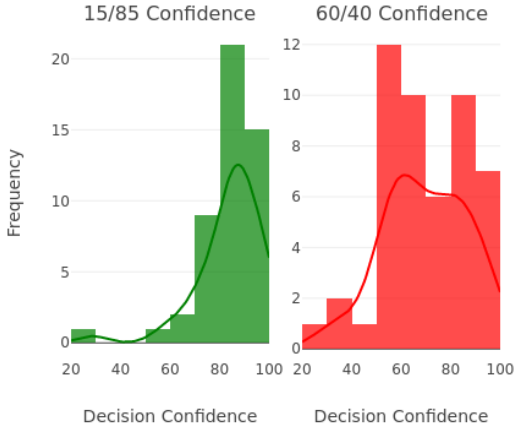
2.1 Differential Belief Updating in Beads Task

The Beads Task was implemented with two probability conditions to measure evidence gathering behavior:

- **High-certainty condition:** 15-85% jar probability ratio, creating clearer distinction between options
- **Low-certainty condition:** 40-60% jar probability ratio, requiring more extensive evidence gathering



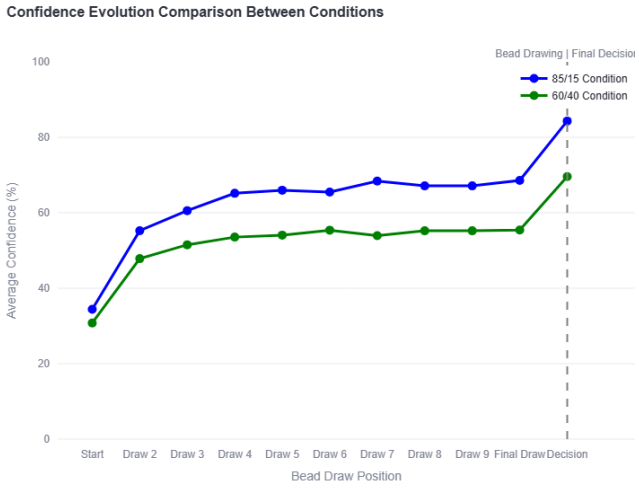
(a) Draws-to-Decision (DTD) distribution showing clear separation between high and low certainty conditions



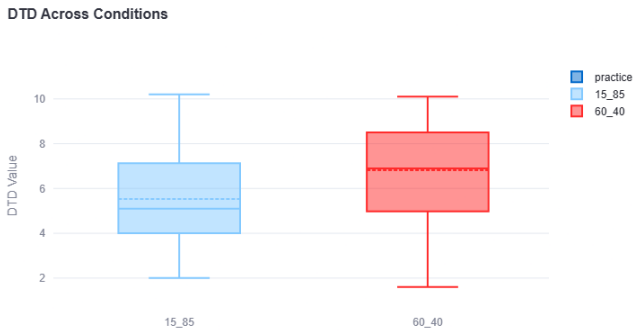
(b) Confidence ratings showing appropriate metacognitive calibration to task difficulty

Figure 1: Draws-to-Decision Analysis | Confidence Rating Analysis

Key Finding:
Participants required significantly more beads in the low-certainty condition ($M = 6.82$, $SD = 2.13$) compared to the high-certainty condition ($M = 5.53$, $SD = 2.07$). Confidence ratings were appropriately calibrated, showing higher confidence in the high-certainty condition.



(a) A consistent gap is observed between confidence levels across all trials, with the 60/40 condition showing lower confidence compared to the 80/20 condition.



(b) The 60-40 condition shows a higher mean DTD and greater variability compared to the 15-85 condition

Figure 2: Confidence Evolution b/w Conditions | DTD Across Conditions

2.2 Schizotypy Correlation Analysis

We investigated how belief updating relates to schizotypal traits using the Oxford-Liverpool Inventory of Feelings and Experiences (O-LIFE), which measures:

- **Unusual Experiences (UE):** Perceptual aberrations and magical thinking
- **Introvertive Anhedonia (IA):** Reduced pleasure and social withdrawal
- **Cognitive Disorganization (CD):** Thought disorder and attention difficulties
- **Impulsive Nonconformity (IN):** Impulsive and eccentric behaviors

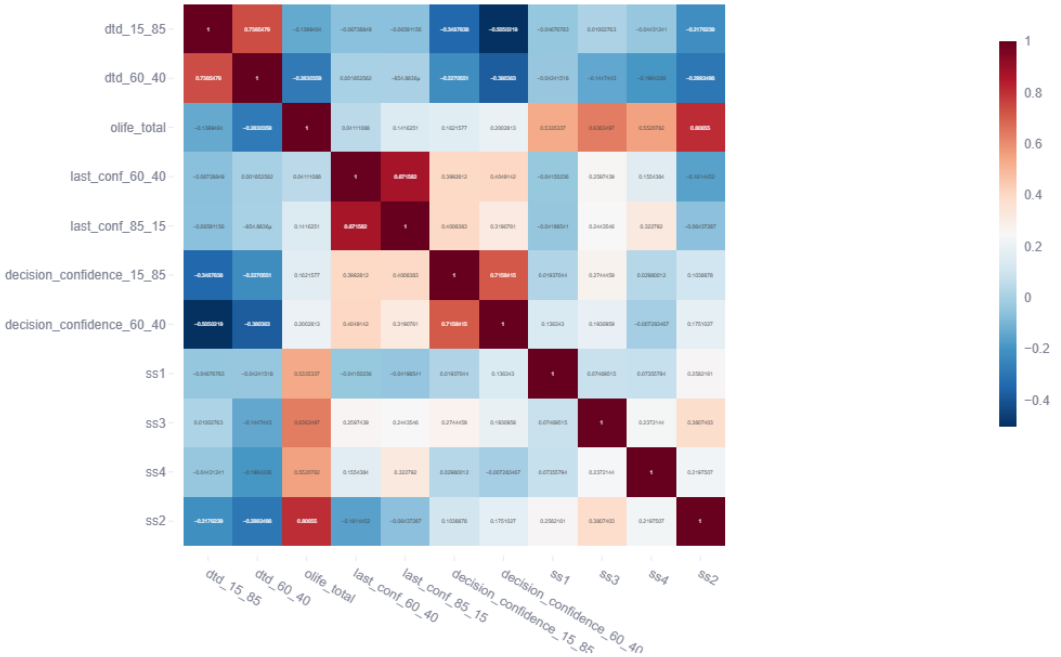
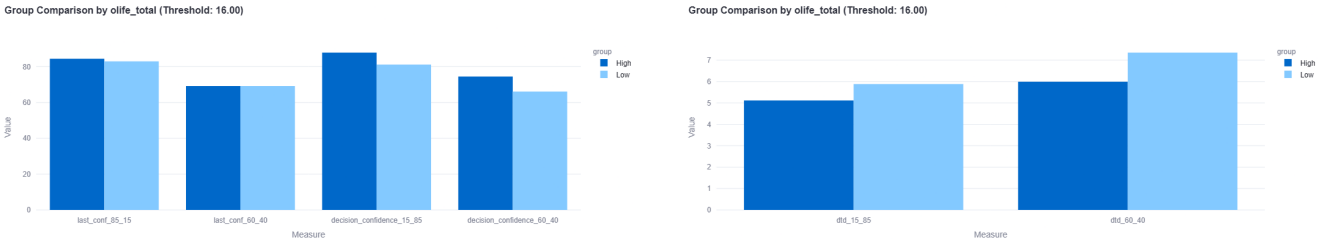


Figure 3: Correlation between Draws-to-Decision (DTD) and total O-LIFE scores showing negative relationship



(a) DTD vs. Unusual Experiences showing strong negative correlation

(b) DTD vs. Cognitive Disorganization showing significant relationship

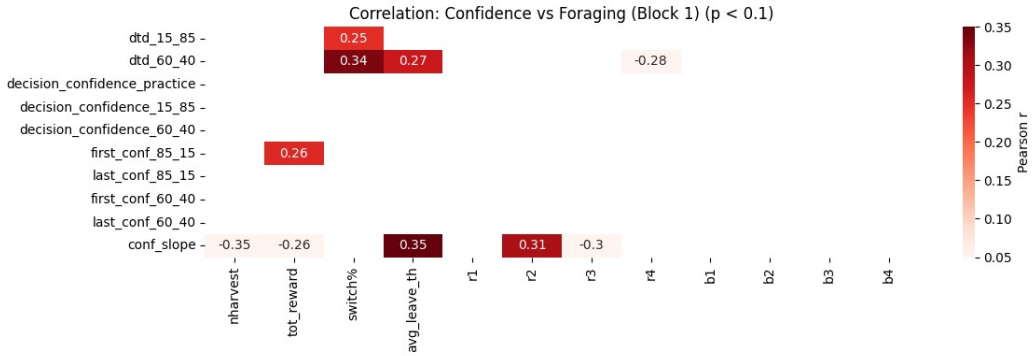
Figure 4: Subscale Analysis: Unusual Experiences | Subscale Analysis: Cognitive Disorganization

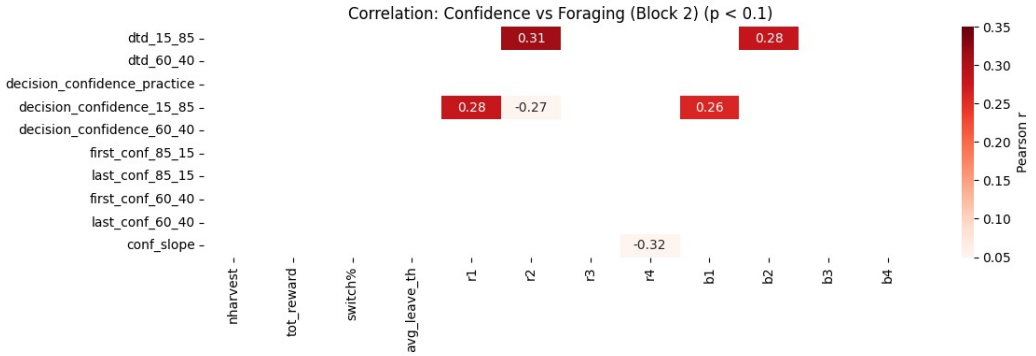
Key Finding:
Higher schizotypy scores were associated with gathering less evidence before making decisions—particularly in the UE and CD dimensions. This mirrors the "jumping to conclusions" bias documented in schizophrenia and suggests that positive symptom-like experiences and cognitive disturbances most strongly relate to hasty decision-making.

2.3 Cross-Task Validation: Beads vs. Foraging

To establish convergent validity, we compared the Beads Task with our novel Tree-based foraging task, examining belief updating and strategic exploration across paradigms:

Beads Task Measures	**Tree Task Parameters**
Draws-to-Decision (DTD)	Adaptation rate (r2)
Decision confidence	Exploration-exploitation balance (b2)
Decision accuracy	Reward harvesting efficiency





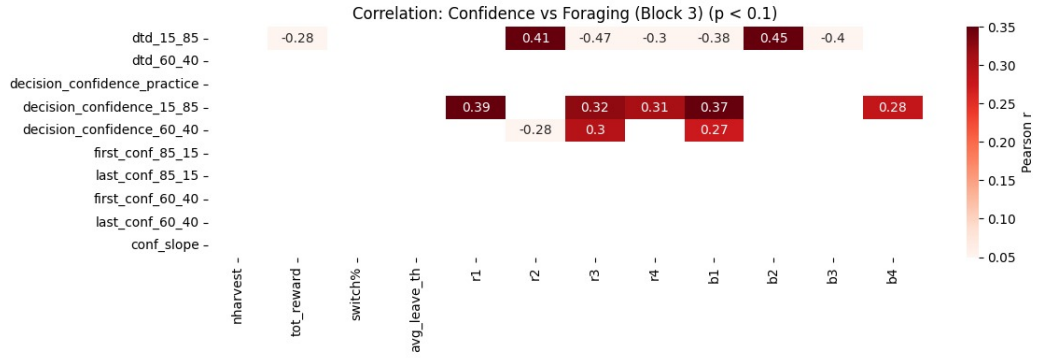


Figure 5: Correlation Between Metrics from the Beads Task and the Foraging Task

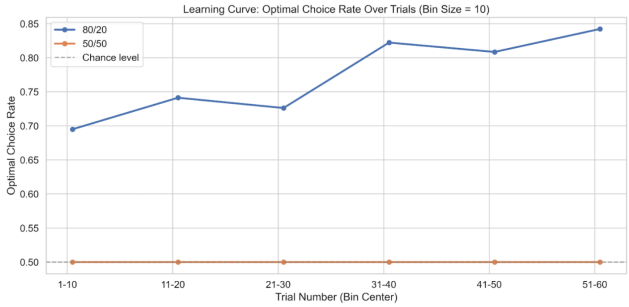
Key Finding:
Our analysis revealed that evidence gathering behavior (measured by DTD) had context-dependent effects on foraging performance:

- **Simple Environment (3 Trees):** Higher DTD correlated with better adaptation to contingency changes ($r = -0.1885$), suggesting deliberative decision-making benefits simple environments.
- **Moderate Complexity (5 Trees):** Higher DTD led to over-commitment to non-rewarding patches ($r = +0.1585$ for visits/harvests), indicating cautious decision-making becomes less optimal as complexity increases.
- **High Complexity (8 Trees):** Higher DTD predicted poor resource allocation (oversampling non-rewarding patches, underexploiting fast ones) and weaker adaptation after reward shifts, demonstrating that excessive caution becomes maladaptive in complex environments.

These findings suggest that while deliberative decision-making benefits simple tasks, the "jumping to conclusions" bias observed in schizophrenia might paradoxically enhance adaptation in complex, rapidly changing environments.

2.4 PRL Task Analysis

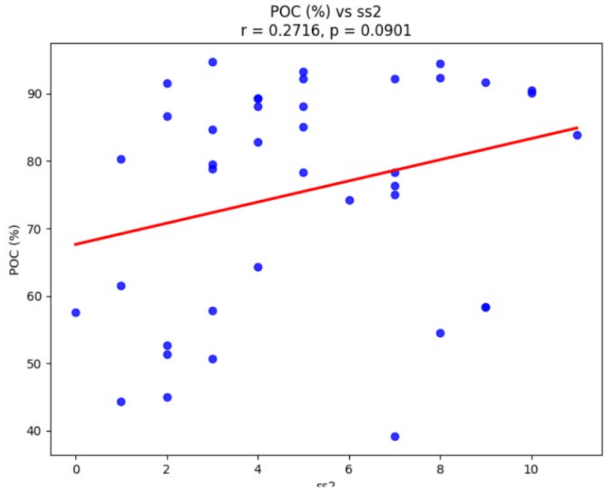
(a) In the 80/20 block, response times drop steadily from about 370 ms in trials 1–10 to 295 ms in trials 51–60, showing that as participants learn which shape pays off more often, they decide faster. By contrast, in the 50/50 block, response times stay around 305–315 ms with only small ups and downs, reflecting continual uncertainty when both options are equally rewarding



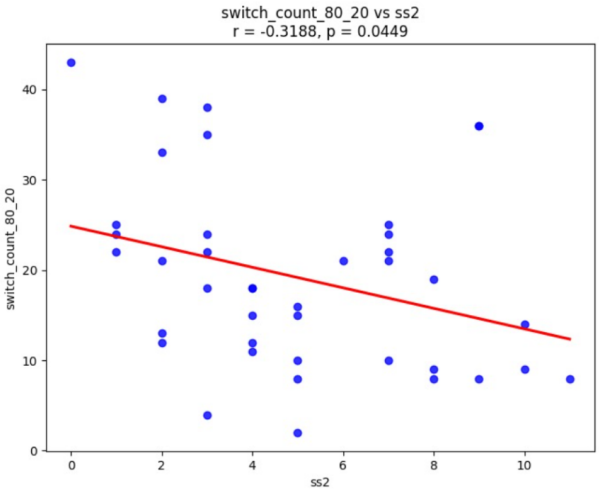
(b) The optimal-choice rate climbs from 0.70 to 0.84 over the 80/20 block, confirming that participants gradually favor the high-reward shape. In the 50/50 block, it remains flat at 0.50 (chance), since no option is better. Together, these curves illustrate swift learning and speeding decisions under clear reward differences, versus stable, chance-level choices when outcomes offer no guidance

Figure 6: Response Time Analysis | Learning Rate

2.5 Cross-Task Validation: PRL vs. Foraging



(a) This result shows that one might expect individuals with higher cognitive disorganisation (ss2)—reflecting attentional and decision-making difficulties—to perform worse. However, the trend suggests a slight increase in optimal choice behaviour with higher SS2 scores. This could imply that in some cases, individuals with disorganised cognition may rely more on fixed or rigid strategies that, coincidentally, align with optimal choices in this context.



(b) This result shows that individuals with higher overall schizotypy scores may show reduced behavioural flexibility, as reflected by their decreased switching in an environment that rewards adaptive strategy changes. This result indicates that individuals with higher cognitive disorganisation switched less frequently between options in the game where one choice was clearly more rewarding, likely reflecting reduced flexibility and impaired feedback integration.

Figure 7: POC vs ss2 | Switch count vs ss2

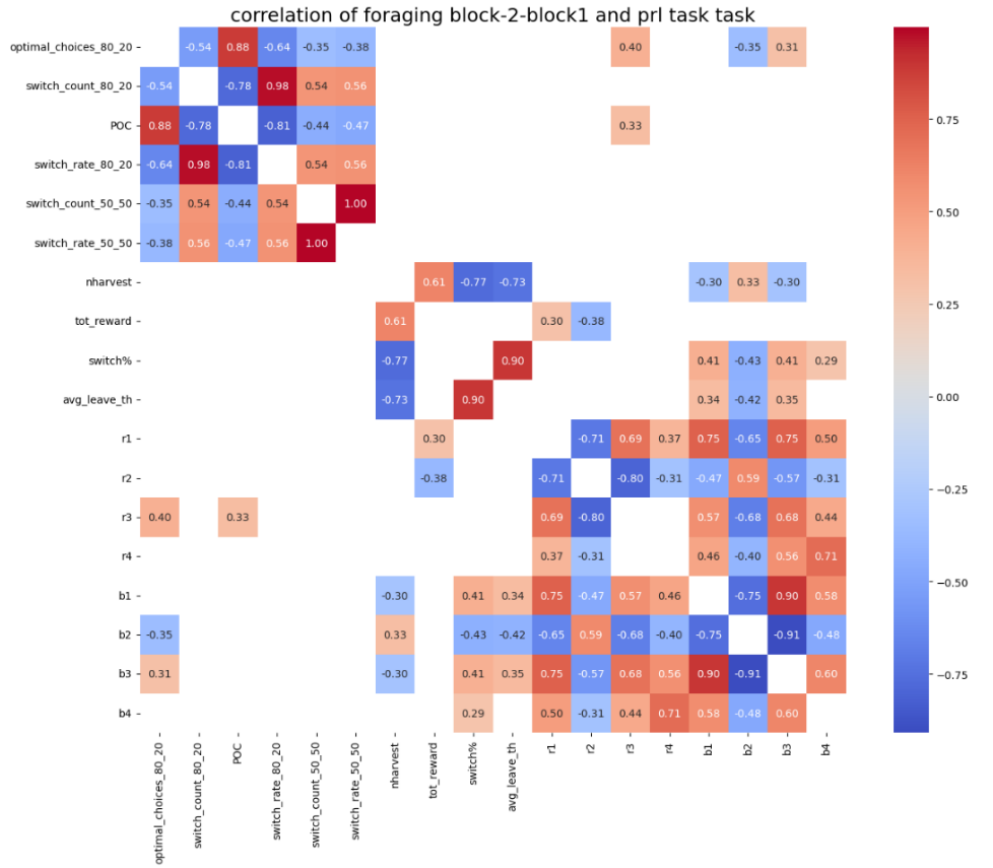


Figure 8: Correlation between PRL and Foraging task: Participants who show stronger reward preference (either by visiting/harvesting more from better patches or by choosing the optimal option more frequently) tend to perform consistently across both foraging and PRL tasks

3 Conclusions & Implications

Our research demonstrates that traditional cognitive tasks, while valuable for isolating specific processes, may not fully capture the complexity of real-world decision-making in schizophrenia. Key insights include:

- The Beads Task confirmed the "jumping to conclusions" bias correlates with schizotypal traits
- Cross-task correlations validate our novel Tree Task as a more ecologically valid measure
- Integrated assessment of multiple cognitive processes provides richer insights into real-world functioning
- Participants showed clear reward learning in the PRL task (80/20), while increased switching in the 50/50 block reflected adaptive exploration under uncertainty
- The PRL paradigm effectively separates reward-based learning from uncertainty-driven belief updating using simple, robust metrics

These findings suggest that cognitive remediation approaches should target integrated cognitive processes rather than isolated domains, potentially improving functional outcomes for individuals with schizophrenia.

Research Team Contributions

Task Development	Equal contribution by everyone (Sanyam Shivhare (220972), Mridul Gupta (220672), Mudit Agrawal (220673), Kritnandan (220550), Karan Jangid (220500), Choudhari Aarsh (220317))
Data Collection & Analysis	Equal contribution by everyone
Documentation	Equal contribution by everyone