Study shows monkeys are capable of complex deliberation and careful decision-making

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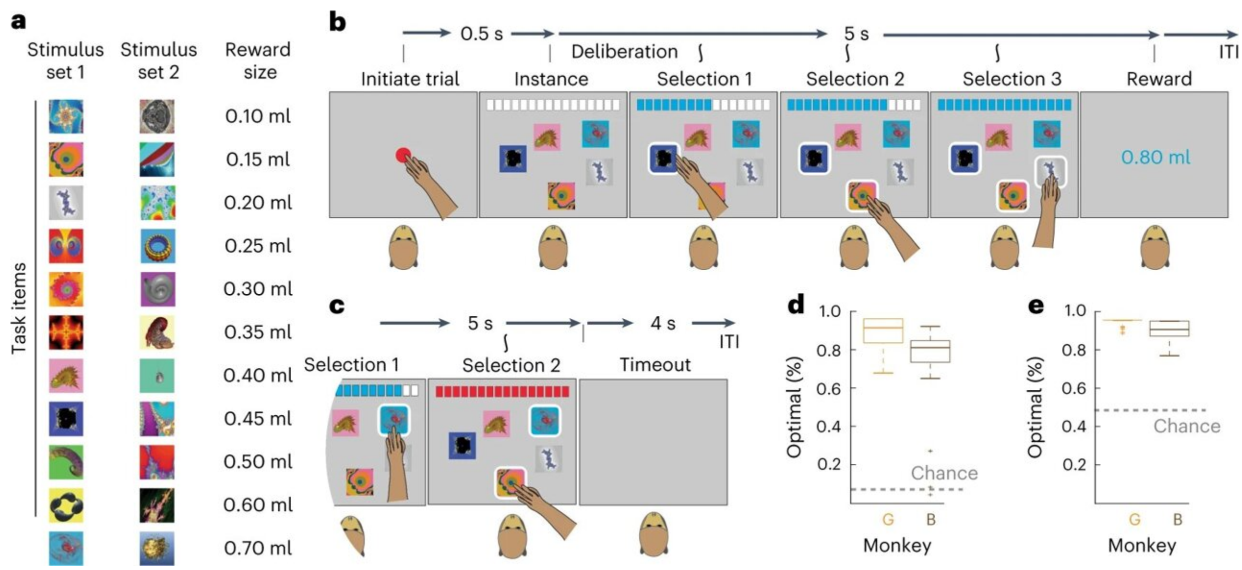

Knapsack task and basic optimizing behaviors. **a**, List of fractal images that symbolized the items in stimulus set 1 (left column), stimulus set 2 (middle column) and the items' reward sizes (right column). **b**, Schematic representation of the knapsack task. The animals initiated the knapsack trials by touching a red central target. After initiation, an instance was displayed and remained on the screen for 5 s. During those 5 s, the number and identity of the selections were determined by the animal. When they selected an item, it was highlighted, it could not be deselected and the volume associated with the selection was added to the virtual knapsack at the top of the screen. If the sum of the items was less than or equal to 0.8 ml, then the sum was delivered at the end of the 5-s period. **c**, Schematic representation of a knapsack trial when animal exceeded 0.8 ml. In this case, no reward was delivered and a 4-s timeout was imposed. **d**, An additional fractal image was introduced as a 'positive control' that promised a reward equal to the knapsack limit. Bar graphs show the percentage of positive control trials when the animals selected the positive control item and nothing else. This response is optimal. Orange and brown bar graphs show data from monkeys G and B, respectively. The gray bar graph shows the percentage of positive control trials that an agent using a random sampling strategy chooses the positive control image and nothing else. Error bars are ±s.e.m. across n = 791 and 620 trials for monkeys G and B, respectively. **e**, An additional fractal image was introduced as a 'negative control' that promised no reward. Box plots show the percentage of negative control trials when the animals exhibited optimal behavior, here defined as not including the negative control item in the solutions. Orange and brown box plots show data from monkeys B and G, respectively. The gray dotted line shows the percentage of negative control trials that an agent using a random sampling strategy avoids including the negative control item. n = 36 and 26 sessions for monkeys G and B, respectively. Box plots show the median (line), quartiles (boxes), range (whiskers) and outliers (+). Credit: *Nature Neuroscience* (2023). DOI: 10.1038/s41593-023-01307-6

A paradigm-shifting study published today in *Nature Neuroscience* shows that, just like humans, monkeys are capable of complex deliberation and careful decision-making. The study is the first to show that monkeys can think deeply about a problem and consider combinations of factors such as costs, consequences and constraints. In doing so, monkeys can find optimal outcomes rather than impulsively reaching for the first available option.

"Humans are not the only animals capable of slow and thoughtful deliberation," said senior author William Stauffer, Ph.D., assistant professor of neurobiology at the University of Pittsburgh School of Medicine. "Our work shows that monkeys have a rich mental state that renders them capable of intelligent thinking. It's a new paradigm for studying the neurophysiological basis for deliberative thought."

Consider a fundamental question: how do we, as humans, think about what we want? What happens in our brains when we close our eyes and deliberate over complex questions, such as who to spend time with or what to study at school? And are other animals, including monkeys, capable of the same complexity of thought?

Several decades ago, the Nobel Prize laureate Daniel Kahneman, Ph.D., revolutionized the field of behavioral economics with Prospect Theory. In his book, "Thinking Fast and Slow," he postulated that humans employ two distinct systems of thinking: one nearly instantaneous that happens automatically, and the other much slower conscious logical reasoning that requires more mental effort.

Kahneman dubbed the first, effortless, type of thinking as 'fast' and the second as 'slow." Slow, effortful thinking enables us to write music, develop scientific hypothesis and balance our checkbooks.

As it turns out, humans' slow thinking is not unique.

By presenting monkeys with combinatorial optimization problems in what Pitt neuroscientists dubbed the 'knapsack task' and rewarding the animals based on the value of the submitted solutions, researchers showed that monkeys employed sophisticated mathematical reasoning and used efficient computational algorithms to tackle complex problems.

The scientists discovered that the animals' performance and speed of deliberation was dependent on the task's complexity, and that their solutions closely matched those generated by efficient computer algorithms designed specifically to solve the optimization problem.

"Results from this work will contribute neurophysiological evidence to enlighten centuries of discussions about dual process theories of the mind, the structure of thoughts, and the neurobiological basis of intuition and reasoning," wrote Stauffer in an accompanying research briefing.

More information: William Stauffer, Computational complexity drives sustained deliberation, *Nature Neuroscience* (2023). DOI: 10.1038/s41593-023-01307-6.
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