

Decision Neuroscience

New Directions in Studies of Judgment and Decision Making

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ABSTRACT—*Investigations of decision making have historically been undertaken by different disciplines, each using different techniques and assumptions, and few unifying efforts have been made. Economists have focused on precise mathematical models of normative decision making, psychologists have examined how decisions are actually made based on cognitive constraints, and neuroscientists have concentrated on the detailed operation of neural systems in simple choices. In recent years, however, researchers in these separate fields have joined forces in an attempt to better specify the foundations of decision making. This interdisciplinary effort has begun to use decision theory to guide the search for the neural bases of reward value and predictability. Concurrently, these formal models are beginning to incorporate processes such as social reward and emotion. The combination of these diverse theoretical approaches and methodologies is already yielding significant progress in the construction of more comprehensive decision-making models.*

KEYWORDS—*decision making; judgment; choice; neuroscience; economics*

The study of decision making has as its goal the understanding of our fundamental ability to process multiple alternatives and choose an optimal course of action. A “good” decision is one in which the best available course of action is chosen in the face of characteristic uncertainty about the consequences. While some decisions are straightforward, many are more difficult, either because the stakes may be high—such as the choice of a mate or a choice among different potentially life-saving medical treatments—or because there are difficult trade-offs to make between competing options—such as those usually observed between quality and price of goods or the respective benefits and side effects of a drug. To complicate matters, often our decisions are additionally dependent on how others might respond—for

example, when we are deciding whether to ask someone on a date or entering a business negotiation.

Disparate approaches to decision making have all made important advances, but there has been relatively little integration of findings, with researchers often unaware of empirical discoveries and theoretical approaches from other areas that nevertheless have immediate relevance for their own investigations. Economic approaches have primarily focused on describing idealized, optimal decision behavior, while in recent times the emergence of psychological models of decision making have offered more accurate descriptive accounts by taking into consideration the motivations and constraints of the human information-processing system. In parallel, neuroscientific studies have used both single-cell approaches (in which activity is recorded directly from small groups of neurons) and neuroimaging to examine lower-level perceptual choices in many animals, but the micro-level decisions typically investigated in such studies are often difficult to reconcile with the decisions made by humans in everyday life.

However, a new, interdisciplinary field, popularly known as neuroeconomics, is now striving to better understand decision-making behavior by taking into account the cognitive and neural constraints on this process, as investigated by psychology and neuroscience, while also utilizing the mathematical decision models and multiplayer tasks that have emerged from the field of economics. By using the complementary strengths of different disciplines, the neuroeconomic approach offers a promising avenue to examine decision making at different levels of analysis and, eventually, to arrive at a comprehensive account of how decision making operates.

THE NEURAL BASIS OF INDIVIDUAL DECISIONS

The “maximize utility” decision rule (Fig. 1) is the core of modern economic theories of rational behavior and can be summarized in a succinct equation that represents the evaluation of each course of action:

Subjective expected utility = $\sum p(x_i)u(x_i)$, where p represents the likelihood of a particular alternative, and u represents the subjective value of that alternative.

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$$(0.25 * 100) + (0.75 * 40) = 55$$

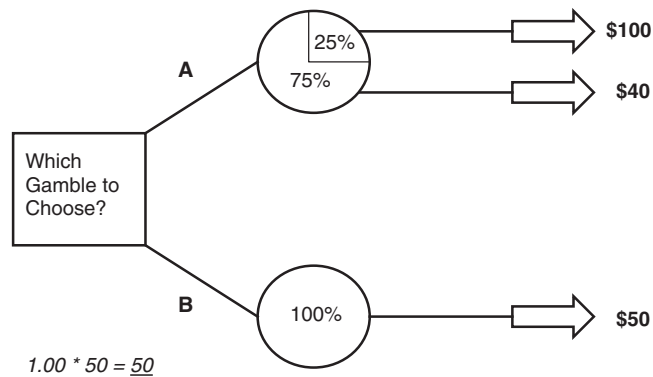


Fig. 1. Choice of two gambles as modeled by formal decision theory. The canonical subjective expected utility (SEU) model proposes that, to make a choice, each course of action should be evaluated by multiplying a subjective valuation of its different possible consequences (in this case, different dollar rewards) by their probabilities of occurrence, and the gamble with the highest expected utility should be chosen. Taking gamble A, in this example, results in a 25% chance to win \$100 and a 75% chance to win \$40 (giving a subjective utility value of 55, according to the equation at the top), whereas gamble B results in a 100% chance of winning \$50 (subjective utility value of 50). SEU theory would predict that the decision maker would choose gamble A, since its subjective utility is higher.

The concept of the expected utility of a decision alternative—the result of multiplying the alternative’s subjective value by its probability, is a crucial one, as it enables the decision maker to compare and contrast options specified in different formats. For example, if one is offered the choice between a new television and a weekend vacation of equal monetary value, how does one compare the subjective value of the two options? An independent metric for assessing reward value is necessary for a system that must often choose between rewards delivered in different modalities.

An extensive literature has demonstrated the limits of subjective expected utility theory (SEUT) as a descriptive account of decision making (Kahneman, Slovic, & Tversky, 1982); but as a well-specified mathematical model and at least a good first approximation of decision making, SEUT has offered a useful starting point for the investigation of decision making’s neural basis. Of particular interest to psychologists and neuroscientists are the probability, value, and utility parameters of the SEUT function. Does the brain make decisions in accordance with the tenets of SEUT? And, importantly, can brain data be used to distinguish between competing psychological theories of decision making and choice, providing evidence above and beyond that obtainable from behavioral studies?

Value and Probability

Several decades of animal research have focused on the neural bases of reward and punishment and have identified a number of systems that are consistently responsive to value. The early focus of this research was on *experienced utility*—the reaction to reward when it is received—but there has since been a gradual shift toward the investigation of *decision utility*—the expectation of consequence at the time the decision is being made. For example, single-cell recording techniques have discovered responses in both dopamine neurons (Tobler, Fiorillo, & Schultz, 2005) and the frontal cortex (Roesch & Olson, 2004) that scale reliably with reward magnitude, demonstrating neural signatures of the encoding and processing of reward signals (see Fig. 2).

Findings such as these have informed modern neuroimaging studies of human reward processing. In particular, the striatum, an area of the brain rich in dopaminergic neurons, reliably activates in response to earned monetary reward—for example, in a study in which participants had to gamble on the uncertain

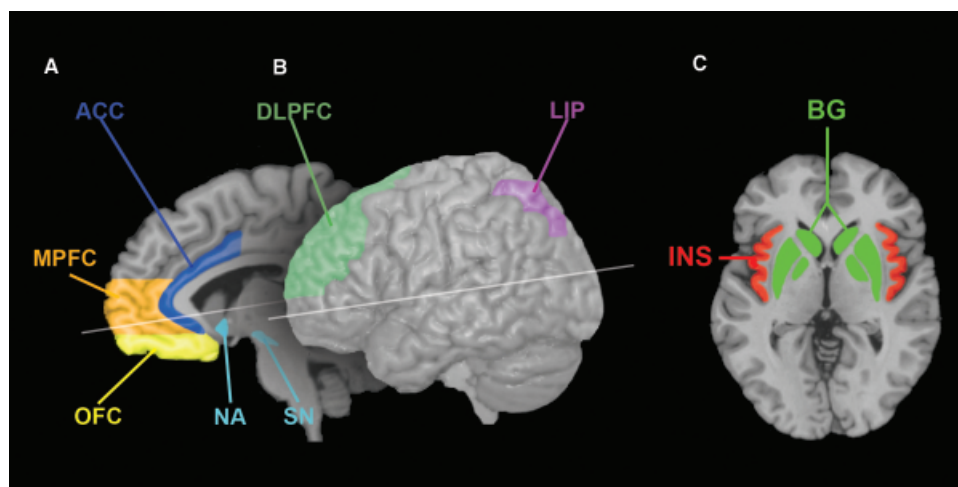


Fig. 2. Map of brain areas commonly found to be activated in decision-making studies. The sagittal section (A) shows the location of the anterior cingulate cortex (ACC), medial prefrontal cortex (MPFC), orbitofrontal cortex (OFC), nucleus accumbens (NA), and substantia nigra (SN). The lateral view (B) shows the location of the dorsolateral prefrontal cortex (DLPFC) and lateral intraparietal area (LIP). The axial section (C; cut along the white line in A and B) shows the location of the insula (INS) and basal ganglia (BG).

value of a stimulus (Delgado, Locke, Stenger, & Fiez, 2003)—as well as in response to primary rewards such as the appetitive value of food (McClure et al., 2004). It seems likely that the striatal involvement in reward is related to the midbrain dopamine systems, which play a critical role in value assessment by signaling when an error is made in reward prediction, thus providing a link between theories of reward, theories of learning, and theories of decision.

In contrast to the large amount of research on reward, relatively little research has been done on judgments of probability. However, one recent neuroimaging study presented subjects with cues indicating both the likelihood and value of upcoming monetary rewards and showed that activity in the medial prefrontal cortex was related to the subjective probability of obtaining the reward (Knutson, Taylor, Kaufman, Peterson, & Glover, 2005). This suggests that the probability-estimation process may indeed be separable from that of reward assessment.

Utility

The tantalizing evidence of potentially distinct systems for the processing of reward and probability lends support to the SEUT model as a useful representation of the neural processes at play in decision making, as this model also implies separable processes for reward and probability measures. Studies have now begun to investigate the neural signatures of the expected-utility signal itself.

Experimental work with animals has revealed brain areas that appear to directly encode the utility of a stimulus. In one study, monkeys were placed in front of a computer screen and presented with two colored squares, each of which represented a different reward schedule of juice. Electrode recordings demonstrated that specific neurons in the lateral intraparietal area (LIP) were representing the utility signal for each target and that the monkey's eye-movements on each trial were in accordance with this utility measure, suggesting a strong relationship between neural metrics of utility and decision behavior (Sugrue, Corrado, & Newsome, 2004). Also, these neurons seem sensitive to direct manipulations of utility, exhibiting combined effects of value and probability as predicted by the SEUT model (Platt & Glimcher, 1999).

The LIP has been well characterized as a motor-preparation area, and therefore it seems probable that the utility measure is computed elsewhere in the brain and shunted downstream to LIP for action selection, and studies in both humans and animals are now testing for brain activity that scales directly with decision-related expected utility. In a functional magnetic resonance imaging (fMRI) experiment, Knutson et al. (2005) manipulated both reward magnitude and probability and found that activation in striatal reward areas indeed correlates with expected utility, showing that utility-like signals can be found outside motor-preparation areas like LIP. Additionally, a particularly interesting recent study (Padoa-Schioppa & Assad, 2006) found that neurons in the monkey orbitofrontal cortex encode the subjective value of

various decision alternatives (in this case, juice vs. water), independent of any action required to select between them, thus providing evidence for a neural decision-making mechanism not tied to motor response and again suggestive that the classical utility approach may be a useful model of how choice alternatives are represented by neural encoding mechanisms.

What unites all of the aforementioned studies is the use of classical, formal economic models to examine the underlying psychological and neural basis of decision making; the results of these studies suggest that the various decision processes implied by the classical model (probability estimation, reward and loss valuation, utility calculation) may indeed be instantiated in the brain. This is important, as it provides some empirical support for these formal models of decision making and offers a very useful framework for examining the neural basis of decisions and choices.

Neural and Theoretical Models

The real benefit, and potential transformative advantage, of the neuroeconomic approach is in the combination of methods: using the tools of neuroscience to empirically examine the predictions of formal economic models. To date, research into the neural basis of utility has largely been a brain-mapping endeavor—that is, identifying the brain areas that may underlie the computations of probability, reward, and expected utility, respectively. This enterprise represents a not inconsiderable achievement and is a necessary precursor to work that will use these neural findings to build more accurate decision models. However, even at this early stage, the presence of distinct neural areas that appear to correspond to the weighting and summing processes underlying the classical approach can help in distinguishing between alternative models of decision making. For example, recent research has proposed that choices are often made via simple rules of thumb, suggesting an alternative model to the classical approach (Brandstatter, Gigerenzer, & Hertwig, 2006). Therefore, demonstrating that brain areas do indeed weight and sum probabilities and values is an important piece of evidence that the family of utility-theory models may well be an accurate representation of how the brain decides between alternatives.

Further, neuroimaging work on reward processing has demonstrated neural activity that conforms to predictions of psychological decision theories such as prospect theory (Kahneman & Tversky, 1979). One important principle of this theory is that people evaluate the outcome of decisions based on a flexible reference point; this would predict that the neural systems responsible for utility assessment should be responsive to relative gains and losses rather than to absolute levels. Recent studies using both fMRI (Breiter, Aharon, Kahneman, Dale, & Shizgal, 2001) and electroencephalogram (Holroyd, Larsen, & Cohen, 2004) have provided support for this prediction: Both experiments demonstrated that neural signatures of reward are determined by the value of the outcome relative to the range of possible outcomes rather than by the objective value of the outcome itself.

NEURAL BASIS OF SOCIAL EXCHANGE

Much of the research described in the previous section, characteristic of a common approach utilized by psychology and neuroscience, examines decision tasks with clearly defined probabilities and outcomes—for example, choosing between monetary gambles. However, another class of decisions has been investigated by economics—decisions that, although beguilingly simple, require complex reasoning about the motivations and strategies employed by other players. Tasks involving such decisions offer a useful window into more complex forms of decision making that may better approximate many of the choices we make in real life.

In a similar fashion to the framework provided by utility theory for studying individual decisions, game theory offers well-specified models for the investigation of social exchange. However, much of the decision behavior actually observed in social-exchange tasks deviates, often quite substantially, from the predictions of the standard game-theoretic model, suggesting that psychological and neuroscientific approaches may help our understanding of these decisions and judgments. Recent research has combined these tasks with neuroimaging in an effort to gain a more detailed picture of social decision making.

One strand of neuroimaging research has made an important contribution by showing that social exchange can act directly on the brain's reward system, providing further evidence for a flexible reward system and a common metric that can be used to compare across reward types. For example, Rilling, Sanfey, Aronson, Nystrom, and Cohen (2004) have shown that the striatum, which (as described previously) is active for basic rewards, appears to also encode more abstract rewards such as the positive feeling garnered by mutual cooperation in a social decision-making task known as the Prisoner's Dilemma. Similarly, de Quervain et al. (2004) used positron-emission tomography imaging to examine punishment of transgressing social norms in an economic-exchange game and identified reward-related brain areas associated with punishment of nonreciprocators. Other findings have been reported in a relation to exhibitions of trust in an investment game (King-Casas et al., 2005): A neural signal corresponding to the "intention to increase trust" was isolated, showing that abstract rewards like trust are encoded in reward-related areas.

In a related vein, a neuroimaging study (Sanfey et al., 2003) examined behavior in a classic economic task, the Ultimatum Game, in which two players share a sum of money between them. This game demonstrates that people will often sacrifice monetary reward in order to punish a player who treats them unfairly. The researchers found a brain area—the anterior insula—that exhibited greater activation as the unfairness of the offer increased. Further, this area was more active when playing with another human than with a computer partner, and, importantly, the activation of this area in combination with others reliably predicted the player's decision whether to cooperate or not. The anterior insula is typically activated when people are confronted

with aversive physical stimuli, suggesting that more basic sensory areas can be recruited for higher-level decisions.

Additionally, many of the imaging studies of social exchange have demonstrated the large influence of automatic processes, such as emotions, on these types of decisions. In contrast to the standard economic model, which presupposes the operation of a single rational information processor, current research is examining how the twin systems of automatic and controlled processing may cooperate—and sometimes compete—in decision making. The degree to which these subsystems are biologically distinct is an area of hot debate, but data from neuroimaging studies can not only provide a window onto the existence and location of different subsystems but, in addition, potentially facilitate quantitative estimation of the degree of involvement of these systems to better inform utility parameters in formal models.

CONCLUSIONS AND FUTURE DIRECTIONS

The preceding sections review some general ways in which decision neuroscience can make important contributions to the understanding of decision making. These findings provide some traction for measuring physical mechanisms responsible for individual and social decision making and offer the promise of identifying and precisely characterizing both the mechanisms and the factors that influence how they engage and interact.

As with any new approach, there are challenges to address. The component disciplines operate at different levels of analysis and have different theoretical assumptions. More practically, there are important differences in methodology, in particular with regard to the use of deception and monetary incentives. However, at worst, data generated by such a cross-disciplinary approach will be valuable in providing additional constraints, based on our growing knowledge of neural functioning, on any theory that seeks to accurately model decision making; and at best, such data will allow discrimination and modeling of processes that may be difficult to separate at the behavioral level.

The neuroeconomic approach will continue to depend on the diverse strengths of its contributing disciplines and the willingness of its proponents to continue collaborating and communicating. But given the energetic research and promising results currently emerging, it seems likely that the field has real potential for making important contributions to our understanding of decision making, above and beyond what will continue to be learned from work within each discipline independently.

Recommended Reading

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