Multiple Systems in Decision Making

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Neuroeconomics seeks to gain a greater understanding of decision making by combining theoretical and methodological principles from the fields of psychology, economics, and neuroscience. Initial studies using this multidisciplinary approach have found evidence suggesting that the brain may be employing multiple levels of processing when making decisions, and this notion is consistent with dual-processing theories that have received extensive theoretical consideration in the field of cognitive psychology, with these theories arguing for the dissociation between automatic and controlled components of processing. While behavioral studies provide compelling support for the distinction between automatic and controlled processing in judgment and decision making, less is known if these components have a corresponding neural substrate, with some researchers arguing that there is no evidence suggesting a distinct neural basis. This chapter will discuss the behavioral evidence supporting the dissociation between automatic and controlled processing in decision making and review recent literature suggesting potential neural systems that may underlie these processes.

Key words: **neuroeconomics; decision making; multiple systems; dual processing; neural; brain**

Introduction

The emergence in recent years of the neuroeconomic approach to judgment and decision making has offered innovative methods to the study of how we make our everyday judgments and decisions. Neuroeconomics has sought to integrate ideas from the fields of psychology, neuroscience, and economics in an effort to better specify models of choice and decision and, by applying the diverse theoretical approaches and experimental methods from these fields, has already made significant progress in building more complete models of decision making (for reviews, see Refs. 1, 2). For example, the combination of the precise methods of neuroscience, such as brain imaging techniques like functional magnetic resonance imaging (fMRI), along with the detailed mathematical models of economics, such as utility theory, has begun to demonstrate that the brain may indeed compute some decision values in ways similar to those predicted by standard economic models.[3] Research of this nature promises to greatly enhance our understanding of decision making under conditions of both certainty and uncertainty; in addition, such research offers opportunities for the various fields that study this important process to integrate more fully with and allow researchers to become more aware of cross-disciplinary work that may be relevant to their own investigations.

One particular direction within neuroeconomics that has attracted much interest is the growing insight, primarily based on work in psychology and neuroscience, that decision behavior may be best understood as the operation of multiple underlying systems that interact, sometimes in cooperation and sometimes in competition, to form our judgments and decisions.

The study of decision making over the past several hundred years has been largely dominated by economic theories, which generally assume that decisions are made between alternative courses of action based on a rational evaluation of their consequences. Detailed theoretical models have been developed for dealing with many different types of decision situations, for example, the expected utility model for decisions under risk and the discounted utility model for decisions with consequences spread over time. These models have the important properties of being formally explicit, analytically tractable, and can be used to make quantitatively precise predictions about decision making in a wide variety of circumstances. As such, they have provided a strong and unifying foundation for the development of theory about decision making, with an assumption that decisions reflect the operation of a unitary all-purpose information processor.

However, several decades of research on judgment and decision making has produced a wealth of evidence demonstrating that, in practice, these models do

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Ann. N.Y. Acad. Sci. 1128: 53–62 (2008). © 2008 New York Academy of Sciences.
doi: 10.1196/annals.1399.007

not provide a satisfactory description of human behavior. There is an extensive set of literature describing the many ways in which human decision making violates the principles of rationality as defined by the expected utility[4] and discounted utility[5] models. Early work in economics revealed situations (e.g., Ellsberg and Allais paradoxes) whereby behavior violated key axioms of the expected utility model. More recently, psychologists have documented many instances of deviations from rationality.[6] For example, when faced with a decision between definitely receiving $50 or a 50% chance of receiving $110, the majority of people will choose the sure thing, despite its objectively lower expected value. This illustrates the phenomenon of "loss aversion" whereby people place disproportionate weight on losses relative to gains of similar absolute value.[7] When it comes to choice over time, there is also ample evidence of violations of the discounted utility model. Perhaps most importantly, there is strong evidence that discounting is much steeper for short time delays than for longer delays, a phenomenon known as "hyperbolic time discounting."[8]

To better understand the processes that may underlie decision making, it is productive to examine research findings from experimental psychology that are strongly supported by findings from neuroscience. Work in these fields suggests that human behavior is not the product of a single process but rather reflects the interaction of different specialized subsystems. While most of the time these systems interact synergistically to determine behavior, at times they may compete, producing different dispositions for the same information. A major cause of these observed idiosyncrasies of behavior that have been used to challenge the standard economic model may be that these decisions do not emerge from a unitary process but rather from interactions between distinguishable sets of processes. Despite the promise of this approach, however, there have been cautionary notes struck by researchers who argue that the evidence to date for the existence of separable neural subsystems is quite limited.[9]

New research from the nascent field of neuroeconomics has the potential to shed light on the nature of these subsystems by examining the neural processes at work as people engage in judgment and decision making; work in this domain has already yielded interesting insights into how these systems may be organized at a neural level.

Multiple-system Models

While recent innovative research within neuroeconomics has focused on the notion of several decision-making subsystems, the idea of multiple systems of processing is not unique to decision making and has been developed, in strikingly similar ways, by many thinkers in philosophy, psychology, neuroscience, and medicine over the past several hundred years. One of the early proponents of this approach was Renee Descartes who, in *L'Homme,*[10] proposed that the body automatically sent sensory signals to the brain and then, based on these signals, the soul sent volitional commands to be carried out by the body. Wilhelm Wundt, the so-called father of experimental psychology, also hypothesized that consciousness could be divided into two types of processes.[11] In his theory of selective attention, Wundt described voluntary action as a slow, effortful, and conscious process, while involuntary action, in contrast, requires little effort and operates beyond conscious control. This dualist notion of automaticity and volitional control was further incorporated into many information processing models during the cognitive revolution of psychology in the 1970s[12] and has subsequently been integrated into most psychological and neurobiological models of cognition, including information processing,[13,14] reasoning,[15,16] learning,[17,18] and social cognition.[19,20]

Within judgment and decision making, many multiple-processing theories have been proposed, all of which posit different fundamental modes of processing that alternately cooperate and compete in reaching a decision.[12,13,15,21–27] These theories have their roots in diverse domains ranging from personality to reasoning and, as they all posit a two-system framework, should more properly be termed *dual-process systems*. From a psychoanalytic framework, Epstein's theory of personality, referred to as the cognitive–experiential self-theory, posits the existence of two distinct ways by which people adapt to the world.[26] The rational system is a conscious deliberative system based in language and composed of rational beliefs. The experiential system is automatic, operating unconsciously, and comprised of implicit beliefs derived from emotional experiences. Sloman[15] focuses on how people draw inferences, and this model makes the distinction between associative and rule-based reasoning. He argues that associative reasoning is concerned with similarity and temporal contiguity, while rule-based reasoning is symbolic, logical, and makes computations based on specific rules.

Although there are nuances specific to each theoretical conception, for the most part, these dual-process models are all structurally very similar. In general, these models propose the existence of two distinct systems.[21] System 1 has consistently been described as automatic, fast, effortless, unconscious, associative, slow learning, and emotional. System 2 has been described as controlled, slow, effortful, conscious, rule based, fast learning, and affectively neutral. System 1 processes may be as automatic as basic perception and have been associated with baseline functioning. System 2 has been described as more computationally demanding[13] and thus used to monitor and override system 1 when the latter requires more conscious control. A common example of this phenomenon can be found in the experience of driving a car. Driving requires one to learn multiple complex rules and behaviors, such as obeying the local traffic rules, operating the vehicle, and navigating in three-dimensional space. The novice driver must rely on controlled processing by devoting all cognitive resources to these various facets involved in the act of driving. As the level of the driver's experience increases, these tasks become more efficient and are processed by system 1. This allows the experienced driver to perform additional tasks while driving, such as listening to the radio, conversing with a passenger, and all of the many risky activities people undertake while driving. However, as soon as the experienced driver recognizes a problem that cannot be handled by system 1, such as an accident, getting lost, or a malfunction of the vehicle, system 2 can override system 1 and devote more cognitive resources accordingly. This process of overriding an automatic "intuitive" response to a problem using more deliberative reasoning has been studied in the laboratory[28] and using computational modeling.[29,30] We will provide a brief overview of the behavioral evidence supporting the characterization of these two systems.

Evidence for Multiple-systems in Decision Making

The behavioral evidence for dual systems has a rich tradition of empirical research and has amassed an impressive amount of support from a variety of lines of investigation. While the idea of multiple systems inherently implies the possibility of an infinite number of systems, as mentioned above, the majority of the empirical research has focused specifically on two. System 1 has been described as automatic, fast, unconscious, emotional, and slow learning, while system 2, in contrast, has been described as controlled, slow, conscious, affectively neutral, and fast learning. The following section will present a brief, nonexhaustive summary of behavioral evidence supporting these claims from a variety of domains.

Automatic versus Deliberative

Considerable evidence has accumulated in the judgment literature to suggest that people rely on heuristics to make automatic judgments.[22,31] Heuristics are short-cut "rules of thumb" that we use for everyday nonconsequential decisions. For example, if asked to judge the likelihood of rain on a given day, most people would glance at the sky and provide a quick estimate based on previous experience, as opposed to exhaustively poring over meteorological data. In general, these judgments seem to be good enough for everyday use, but they are consistently less "rational" than those made by system 2[32,33] and are subject to certain biases. People are particularly susceptible to relying on these heuristics when they are pressed for time,[34] under cognitive load,[35] in a good mood,[36] or lacking in motivation.[37] When making judgments about probability, people routinely fail to consider base rates,[38] apply statistical reasoning,[39–41] or even apply simple deductive logic.[42] There is even evidence to suggest that the use of either heuristic or rule-based reasoning can be impacted by the use of priming, increasing cognitive load, and manipulating goals.[43]

Fast versus Slow

Kahneman[22] has suggested that system 1 may generate impressions, while system 2 actually forms judgments. Preferences and other preconscious automatic processing of system 1 can influence system 2[44] but also directly lead to judgments that are referred to as "intuitive."[22] Intuitive judgments have received extensive attention[45–49] and there is mounting evidence that these judgments can be made extremely quickly, particularly when they involve inferring social information from a face. For example, affective judgments, such as determining whether or not you like somebody based on their photograph, can be made as quickly as 160 ms.[50] These rapid judgments can also be made when the stimuli have been barely processed within conscious awareness. People are able to infer traits, such as competence or trustworthiness, from faces they have seen for as little as 100 ms.[51] Despite their rapidity, these trait inference judgments have been demonstrated to predict important decisions, such as voter choices in U.S. congressional elections.[52]

Unconscious versus Conscious Deliberation

There is some evidence that conscious deliberation can significantly impact a decision. Previous work has shown that preferences can be changed by conscious deliberation.[46] Students who were forced to contemplate the etiology of their preferences for strawberry jam were less consistent with expert preferences than those who did not. Furthermore, in another experiment, the authors found that students were happier with choices made intuitively than when these were made analytically. More recently, the complexity of consumer decisions has been demonstrated to interact with the amount of attention given to the deliberation process.[53] People were more likely to choose simple products when they spent more time consciously contemplating them and more complex products when they deliberated unconsciously. This pattern was also observed for the satisfaction of the decisions.

Associative versus Rule Based

As discussed above, the distinction between associative and rule-based reasoning has received extensive considerations.[15,16,21] More recently, there is growing evidence suggesting that this distinction also applies to classification learning.[54] Classification learning refers to the process of how we are able to separate objects or events into distinct categories—a process inherent to making judgments. Behavioral evidence has suggested that people may use different strategies to learn simple rules for classification and complex conjunctions, referred to as "information integration." Rule-based classification appears to employ hypothesis generation and testing and rely on language, attention, and working memory systems. This type of learning is susceptible to interference when under cognitive load[55] or pressed for time.[56] The seemingly more difficult information-integration learning does not appear to be affected by these manipulations, and thus does not seem to require the same cognitive faculties as rule-based learning. People seem to be able to detect and learn complex covariation patterns outside of conscious awareness even when these patterns are difficult to discern.[57]

Affective versus Cognitive

Perhaps the aspect of dual-systems that has received the most attention in recent years in judgment and decision-making literature is the distinction between affective-based and cognitive-based judgments. Use of affect in making judgments and decisions has obvious functional significance in learning what can be approached and what should be avoided.[58] These judgments can be subtle, such as in the exposure effect, where stimuli are rated more favorably the more frequently they are presented,[59] even when they are presented outside of awareness.[60] This process of using natural assessments of affective valence as the basis of a judgment has recently been described as the affect heuristic.[61] However, similar ideas have been proposed in other domains. Damasio and his colleagues have proposed that somatic feedback from system 1 processing plays an important role in reasoning and decision making.[62,63] Patients with brain damage to the ventro-medial prefrontal cortex may be impaired in this regard, which may potentially explain their poor decision-making abilities. This theory, referred to as the somatic marker hypothesis, has remained controversial despite its extensive empirical considerations. Bechara and colleagues[63] proposed that these somatic markers can be observed via physiological measures and developed a gambling task to test this hypothesis. They found evidence suggesting that nonconscious somatic cues precede learning of advantageous decisions.

Neural Evidence for Multiple Systems

With the advent of neuroeconomics, discoveries about the neural mechanisms involved in perception, attention, and learning, have begun to drive the development of new, mechanistically explicit models of decision making. In several instances, these models have also begun to make contact with economic theory.[64] This has, in some cases, provided validation of basic principles of economic theory, whereas in others it has begun to provide insight into how and why human behavior deviates from optimality as defined by economic models. Recent neuroscientific research has begun to characterize the engagement of separable neural systems under a variety of conditions in which behavior seems to deviate from the expectations of economic theory.

The distinction among systems with the greatest immediate ramifications for decision making is between those supporting emotion versus deliberation, which closely parallels the distinction between automatic and controlled processes. The nature of emotions has been the subject of intense inquiry of entire fields of science, a full consideration of which is well beyond the scope of this chapter. For present purposes, "emotion" is used to refer to low-level psychological processes engaged by events that elicit strong valenced and stereotyped behavioral responses (e.g., fear is a response to threatening stimuli that leads to freezing or withdrawal). Accordingly, emotions are rapid highly automatic responses to specific stimuli or events, well adapted to some circumstances but not to others. These contrast with the capacity for controlled processing discussed above—the ability to respond flexibly to circumstances, to rationally deliberate about the long-term consequences of our behavior, and to plan behavior accordingly.

While emotional processes, like other automatic processes, share common neural substrates with controlled processes, it is becoming increasingly clear from neuroimaging studies that these different types of processes do involve distinguishable neural components. There is general consensus that high-level deliberative processes, such as problem solving and planning, consistently engage anterior and dorsolateral regions of prefrontal cortex as well as areas of posterior parietal cortex.[29,65–67]

In contrast, automatic processes appear to rely heavily on more posterior cortical structures as well as subcortical systems. Emotional processes, in particular, seem to reliably engage a set of structures classically referred to as the limbic system, which includes brain stem reward-processing mechanisms (such as the ventral tegmental area), areas of the midbrain and cortex to which they project (such as the nucleus accumbens, and ventromedial frontal, orbitofrontal, and anterior cingulate cortex), as well as a number of other areas, such as the amygdala and insular cortex.[68]

Multiple Systems in Neuroeconomics

Neuroeconomics has begun to make progress in outlining how a multiple-system approach might usefully explain decision making. The majority of the work in this area has focused on the affective/deliberative distinction made by the various multiple-system models.

Although the neural mechanisms responsible for deliberative and affective processing are clearly closely interrelated,[69] distinguishing between these processes can nevertheless be useful in constructing more accurate models of decision making and has the potential to shed light on many of the most basic patterns uncovered by behavioral decision theory. These basic patterns include nonlinear probability weighting and loss aversion, as well as a number of other behaviors that challenge the standard economic model, e.g., market and nonmarket interactions between individuals. An example of the latter is behavior in a well-studied decision task known as the Ultimatum Game (UG), first introduced by Guth *et al*.[70] In this game, two players are given the opportunity to split a sum of money provided by the experimenter. One player is deemed the proposer and the other the responder. The proposer makes an offer as to how this money should be split between the two. This player is free to propose any split they want, from abjectly unfair ("I will keep all the money"), to fair ("We will split the money evenly"). The second player (the responder) then must make a decision. They can either accept or reject this offer. If the offer is accepted, the money is split as proposed; the twist is that if the responder rejects the offer, then neither player receives anything. In either event, the game is over.

The standard game theoretic solution to the UG is for the proposer to offer the smallest sum of money possible to the responder and for the responder to accept this offer on the reasonable grounds that any monetary amount is preferable to none. However, considerable behavioral research in industrialized cultures indicates that, irrespective of the monetary sum, modal offers are typically around 50% of the total amount. Responders are also quite consistent. Low offers (of 20% of the total or less) have about a 50% chance of being rejected. This very robust finding is intriguing, demonstrating that circumstances exist in which people are motivated to actively turn down monetary reward (Camerer[71] presents a useful summary of the principal findings).

Of interest to decision-making researchers is why people reject offers. The game is so simple that it is improbable that these rejections are a result of either a failure to understand the rules of the game or an inability to conceptualize a single-shot interaction with a partner. Based on participant reports, it appears that low offers are often rejected following an angry reaction to an offer perceived as unfair.[72] Objecting to unfairness has been proposed as a fundamental adaptive mechanism by which we assert and maintain a social reputation,[73] and the negative emotions provoked by unfair treatment in the UG can lead people to sacrifice sometimes considerable financial gain in order to punish their partner for the perceived slight. Unfair offers in the UG induce conflict in the responder between deliberative ("accept the offer") and affective ("reject the offer") motives, motives that we might expect to see represented in brain areas implicated in deliberative and affective modes of thought, respectively.

To examine this question and more broadly to attempt to better specify the systems involved in the neurobiology of economic decision making, we conducted a neuroimaging study examining the brain's response to fair and unfair offers in the UG, and, in particular, to investigate how these responses were related to the decision to accept or reject in the game.[74] Participants were scanned using fMRI as they played the role of responder in the UG. Prior to scanning, each participant was introduced to 10 people they were told would partner with them in the game. They were informed that they would play a single iteration of the game with each partner, splitting \$10 in each case, and participants were paid directly based on their decisions during the UG rounds. The offers that the participants saw were in fact predetermined, with half being fair (a \$5:\$5 split) and half being unfair (two offers of \$9:\$1, two offers of \$8:\$2, and one offer of \$7:\$3). This distribution of offers generally mimics the range of offers typically made in uncontrolled versions of the game (i.e., involving freely acting human partners). The 10 offers from the computer partner were identical to those from the human partners and were introduced to distinguish between intentional offers made by other players and the same offers made by a random device.

Behavioral results in this experiment were very similar to those typically found in UG studies. Participants accepted all fair offers, with decreasing acceptance rates as the offers became less fair. Unfair offers of $2 and $1 made by human partners were rejected at a significantly higher rate than those offers made by a computer, suggesting that participants had a stronger emotional reaction to unfair offers from humans than from computers.

With regard to neuroimaging, we were primarily interested in the neural response to unfair offers as compared to fair offers. The brain areas showing greatest activation for this comparison were bilateral anterior insula, dorsolateral prefrontal cortex (dlPFC), and anterior cingulate cortex. In bilateral insula, the magnitude of activation was also significantly greater for unfair offers from human partners compared to both unfair offers from computer partners and low control amounts, suggesting that these activations were not solely a function of the amount of money offered to the participant but were also uniquely sensitive to the context, namely perceived unfair treatment from a human. Also, regions of bilateral anterior insula demonstrated sensitivity to the degree of unfairness of an offer, exhibiting significantly greater activation for a $9:$1 offer than an $8:$2 offer from a human partner.

Activation of bilateral anterior insula to unfair offers from human partners is particularly interesting in light of this region's oft-noted association with negative emotional states. Anterior insula activation is consistently seen in neuroimaging studies of pain and distress, of hunger and thirst,[75] and of autonomic arousal.[76] It is striking how often this region has also been implicated in studies of emotion, in particular involvement in the evaluation and representation of specific, negative, emotional states.[77]

In contrast to the insula, dlPFC usually has been linked to cognitive processes, such as goal maintenance and executive control. Thus, the dlPFC activation observed in response to unfair offers may relate to the representation and maintenance of the cognitive demands of the task, namely the goal of accumulating money. An unfair offer is more difficult to accept, as indicated by the higher rejection rates of these offers, and hence higher cognitive demands may be placed on the participant in order to overcome the strong emotional tendency to reject the offer.

If the activation in the anterior insula is a reflection of the responder's negative emotional response to an unfair offer, we might expect activity in this region to correlate with the subsequent decision to either accept or reject the offer. Indeed, collapsing across participants, an examination of individual trials revealed a relationship between right anterior insular activity and the decision to accept or reject. Additionally, it was notable that unfair offers that are subsequently rejected have greater anterior insula than dlPFC activation, while unfair offers subsequently accepted exhibit greater dlPFC than anterior insula, and that this relationship did not hold for any other pair of active brain regions. The conclusion that strategic interactions between individuals involves an interplay between emotion and cognition is underscored by research that has observed activation in brain reward areas related to satisfaction derived from punishing norm violations[78] and related to exhibitions of trust in an investment game.[79]

Of course, as with all brain imaging data, these results are largely correlative, but they do provide hypotheses for further testing, namely that activation of emotion areas, in this case the anterior insula, is related to the negative experience of receiving an unfair offer from another human; as such, it is related to the decision to reject, while activation of frontal, more traditionally deliberative, regions, such as dlPFC, may represent the cognitive goal of accepting an offer in order to earn at least some monetary payoff from the trial. Therefore, in a further set of studies, we have sought to target these neural areas with a variety of methods in order to examine whether accept/reject decisions in the UG could be manipulated via these mechanisms.

As mentioned above, activation of frontal regions to unfair offers in UG studies has been interpreted as a mechanism by which other, more deliberative, goals (such as reputation maintenance or the desire to make money) can be implemented. The dlPFC has long been established as a crucial structure in working memory and cognitive goal maintenance,[29] suggesting its key involvement in top-down deliberative control. Therefore, enhancing the functioning of this brain region should increase the ability to maintain the cognitive goal of the task (i.e., make money by accepting offers, irrespective of how unfair they are) and should thereby increase the amount of acceptances observed. In order to alter functioning of dlPFC in normal healthy adults, we used a technique known as repetitive transcranial magnetic stimulation (rTMS), which delivers short magnetic pulses (via a figure-of-eight-shaped coil that is placed against the head) that penetrate the skull and alter neural processing in a noninvasive reversible way.[80]

We contrasted two conditions in the experiment,[81] rTMS versus sham stimulation, which was accomplished using an identical coil but which did not send an electromagnetic pulse. Participants played the UG as outlined above, while both receiving and not receiving stimulation. Therefore, we could investigate the precise nature of the involvement of dlPFC by assessing decision making both when dlPFC is normally involved in the process and when it is facilitated. We found that, as predicted, UG acceptances were significantly higher for participants when active stimulation was applied as compared to when sham stimulation was used. It should be noted that rTMS is still rather a crude tool in terms of effects and ability to spatially localize the stimulation, and it is difficult to know precisely the nature of the change in neural function caused by this technique. However, at worst, research of this nature provides some interesting converging evidence, and, as the reliability of the technique increases, it will surely become more useful.

In concert with this investigation of the deliberative system, we have also used experimental methods to prime the affective system. Our initial brain imaging experiment demonstrated that the decision to reject offers in the UG is strongly correlated with increases in activation of the anterior insula, a brain structure known to be selectively involved in negatively valenced emotions.[82] Therefore, to directly investigate the relationship between negative emotional states, activation of the anterior insula, and decisions to reject unfair offers in the UG, we used experimental techniques to prime negative emotional states prior to playing the game and then observed the effect of this priming on decisions made with regard to unfair offers.

Previous studies have shown that experimentally priming anger, for example, can influence both attributions of responsibility and extent of punishment,[83] demonstrating that emotional priming can affect performance of an unrelated task. We expected that priming negative emotional states, which are known to engage the anterior insula, such as sadness, anger, and disgust,[82] would lead to higher rejection rates of unfair offers from a human partner. This experiment,[84] therefore, provided a good test of the initial hypothesis that the negative emotional state induced by an unfair offer is mediated by activation in the anterior insula.

Prior to playing as responder in the standard UG, participants in this study viewed a short 5-min video that was ostensibly unrelated to the UG section of the experiment. These clips had been previously rated as sad, happy, or neutral by a separate group of participants. We found that the group of participants who viewed the sad video (an excerpt from the movie "The Champ") had overall significantly higher rejection rates than those who watched either the neutral or the happy clip, indicating a demonstrable effect of negative mood on "emotional" decisions in the UG. This is important as it shows that subtle and transient emotional states, unrelated to the task at hand, can noticeably affect decisions to accept or reject monetary offers. Further, it suggests a causal relation between negative emotional states, activation of specific affectively specialized brain regions (such as the insula), and eventual decisions. It also suggests that examining decision-making performance in participants with dysregulated emotional processing, such as patients with depression or schizophrenia, may be a useful future avenue of research. Indeed, patients with damage to ventromedial prefrontal cortex, another area implicated in the processing of emotional information, also reject unfair offers more frequently than controls.[85]

These findings outlined above, in conjunction with others such as the emotion–deliberation interactions in hyperbolic time discouting[86] and recent evidence that the framing effect may be mediated by the amygdala (another structure strongly associated with emotional processing),[87] provide an initial toehold for measuring physical mechanisms responsible for decision making in the brain. Such studies offer the promise that we will be able to identify and precisely characterize these mechanisms and the factors that influence their engagement and interaction. Even at this early stage, however, results highlight the fact that decision making appears to involve the interaction among multiple subsystems governed by different parameters and possibly even different principles.

Conclusion

This chapter has reviewed one of the potentially most fruitful themes to which the neuroeconomic endeavor can make important contributions, namely that of the influence of a multiple-system approach to the study of judgment and decision making. With increasing collaboration among decision researchers from across the fields of interest, it appears certain that this approach will lead to more productive avenues of research in the future.

Of course, there are still many outstanding questions, not least the degree to which these proposed systems are truly separable, and it is still unclear how multiple systems are actually instantiated in the brain. Although there is a good deal of evidence, as has been outlined here, for some level of dissociation between dual systems that approximate controlled and automatic processing, respectively, it seems highly unlikely that there are dedicated, independent, subsystems at the neural level that are specific to these modes of processing. Therefore, are the types of systems that have been described at the psychological level (such as the system1/system 2 distinction) good analogues for the way information is organized and processed in the brain? Further, it is still largely unknown under what circumstances the systems cooperate or compete. When there is competition, how and where is it adjudicated? How do these proposed systems map onto the fast versus slow system distinction made by neuroscience?

Clearly more research is needed in this area, and as more is known about the nature of the basic processes involved in decision making, this knowledge will hopefully inform the psychological and economic models in turn. While neuroeconomics is still a far way from providing a full set of answers to these questions, the increasing degree of collaboration between decision-making researchers from many diverse fields offers encouragement for the future and suggests that examining decision making from a variety of perspectives can illuminate all approaches to the study of this topic.

Conflicts of Interest

The authors declare no conflicts of interest.

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