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Introduction

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Background and rationale

The intersection between the fields of behavioral decision research and neuroscience would appear to be fertile ground for interdisciplinary research. Whereas the former is rich in formalized models of choice, the latter is rife with techniques for testing behavioral models at the brain level. Nevertheless, it is only recently that an integrative approach has been embraced leading to the emergence of a full-fledged neuroscience of decision making. For example, in their introduction to *Neurobiology of decision-making*, Damasio and colleagues argued that neuroscience had overlooked decision making as much as it had overlooked emotion (Damasio, Damasio, & Christen, 1996). Although this was an accurate description of the state of affairs in the mid-1990s, it is no longer true today. The intervening years have witnessed a steady narrowing of the gap between the two fields as neuroscientific approaches have been employed ever more frequently to tackle key theoretical and applied issues in judgment and decision making. There is a growing sense that biological data can inform judgment and decision making research by shedding light on its component cognitive and emotional processes (Sanfey, 2007). Our aim with this book has been to provide a coherent framework for distilling some of the key themes that have emerged as a function of this research program, and to highlight what we have learned about judgment and decision making as a result of this process.

Our selection of topics for this book has been determined by three factors. First, we have opted to focus on topics that are theoretically relevant to judgment and decision making researchers, and about which a critical mass of knowledge in the neurosciences has emerged. These topics include reward and loss, risk and uncertainty, and cooperation

and trust, representing the core sections in the current volume. Given the complexity of the problems in these topical areas, it is our belief that a triangulation of approaches is necessary for testing key hypotheses involving brain-behavior correspondences. This is reflected in the diversity of approaches used by our contributors to address these problems, including behavioral experiments, brain imaging, neuropsychology, electrophysiology, computational modeling, and investigations of neurotransmitter systems. Where appropriate, our contributors have also borrowed insights from the animal literature to shed light on human behavior. This multifaceted approach by which decision neuroscientists have studied these topics has already borne fruit by contributing to the development of increasingly sophisticated models for processes that are of interest to behavioral decision theorists. Perhaps chief among those processes are the neural systems underlying the computation of subjective value (O'Doherty & Bossaerts, 2008) and probability (Knutson, Taylor, Kaufman, Peterson, & Glover, 2005), topics of continued intense study in this area.

Second, our choices have been influenced by some of the larger theoretical ideas that have had marked impact on thinking not just among behavioral decision researchers, but also among the greater community of scholars in philosophy, psychology, and economics. Chief among those are ideas involving the existence of multiple systems for judgment and decision making (Evans, 2008), and the significance of emotion for understanding human behavior (Loewenstein, Weber, Hsee, & Welch, 2001). Essentially, the upshot of these developments is widespread agreement among researchers that there is no unitary "module" in the brain for judgment and decision making, but rather multiple parallel processes—including emotional processes—that operate to determine choice

behavior (Bechara, current volume; Christoff, Keramatian, & Smith, current volume; De Neys & Goel, current volume; Sanfey & Rilling, current volume). Given that evidence from the neurosciences has contributed extensively to the development of these ideas in the greater research community (Damasio, 1994; Frank, Cohen, & Sanfey, 2009), a number of our chapters address these influential currents in thinking, in the process evaluating their empirical contributions to understanding judgment and decision making processes, more specifically.

Third, we have ventured somewhat beyond the traditional boundaries of judgment and decision making research and included chapters that discuss the role of judgment and decision making processes in selective higher-order cognitive activities such as planning, creative problem solving, and spontaneous thought. There is much evidence to suggest that higher-order cognitive activities are componential in nature, and that the ability to make optimal judgments and decisions represents one of the critical components for success in such activities. Although traditionally the literatures on planning, creative problem solving, and spontaneous thought have not made explicit contact with work in judgment and decision making, we were motivated to reduce the gap between these areas by highlighting the integral role that judgment and decision making processes play in those mental activities. This approach was made possible because recent evidence from the neurosciences suggests that higher-order mental activities such as reasoning, planning, and problem solving are built on shared neural systems, and that when analyzed in terms of component processes mental activities that appear different at the macro level in fact share commonalities at the micro, neural level (De Neys & Goel, current volume; Vartanian, current volume). In this regard, we are already witnessing how the

neurosciences are redefining concepts and categories invoked in the study of higher-order cognition, as well as their inter-relations.

Organization of the volume

We begin the book with the section entitled *Theoretical Models* that includes two chapters that address issues of general theoretical interest to our readership. Mariano Sigman and Stanislas Dehaene analyze the cognitive and neural architectures of simple decisions. They present behavioral and neural evidence to support their argument that three key puzzles in decision making—decision duration, decision variability, and slow processing—arise from the brain architecture within which decision making occurs. By grounding behavioral features of simple decisions onto basic biology, this chapter sets the stage for interpreting the brain-behavior correspondences discussed in the book. We (Mandel and Vartanian) follow in the next chapter with a discussion of context effects on judgment and decision making, a topic of key concern in the neuroscience of choice (Doya, 2008). Our chapter combines a critical review of the behavioral and neuroscientific literatures on context effects with the presentation of novel experimental data to test hypotheses about their neural and psychological origins. We endeavor to show that current behavioral and neural evidence supports the assertion that the field has entered a stage in which context-dependence of choice must be seen as central to decision theory, and as something that cannot be ignored without incurring a severe loss of explanatory completeness (Goldstein & Weber, 1997).

The next section entitled *Risk and Uncertainty* includes three chapters that address problems in this key topical area for judgment and decision making researchers.

Antoine Bechara offers an historical synopsis that traces the intellectual trajectory of thinking about the role of emotion on decision making from Phineas Gage to the influential *Somatic Marker Hypothesis*. He embraces modern thinking by outlining specific conditions under which emotions can be useful and disruptive to decision making, and describes the multiple cortical systems that comprise the emotional circuitry of the brain, each of which mediating specific aspects of choice under uncertainty. In the chapter that follows Angela Yu distinguishes among various types of uncertainty as a function of their sources. Her approach rests on the assumption that if one were able to offer formal computational descriptions of varieties of uncertainty, then one would be in a better position to understand the brain systems that implement each variant. She offers evidence showing that the neuromodulator acetylcholine plays a critical role in coping with uncertainty in sensory processing and attentional control, embedding her findings in the greater role that acetylcholine plays in expected uncertainty (Yu & Dayan, 2005). Finally, Wim De Neys and Vinod Goel employ a classic problem in the judgment under uncertainty literature—the so-called "Lawyer-Engineer" problem—to show that belief-mediated and normative responses activate dissociable neural systems in the brain. In addition, using neural evidence, they show that when beliefs and norms clash the inability to respond normatively is not a function of lack of awareness regarding that conflict, but rather due to an inability to overcome belief-based responding. Not only does their chapter speak to the engagement of multiple systems of decision making in the brain, but it also demonstrates that the systems that are engaged for heuristic and analytic responding in the context of this decision making task are the same ones that are engaged for similar purposes in the context of deductive reasoning tasks (Goel, 2007). This speaks

to the importance of studying component processes across different tasks that can in turn highlight similarities in neural structure among different mental activities.

Our third section entitled *Reward and Loss* includes three chapters that describe the contributions of neural systems that underlie the computation of reward and loss to judgment and decision making. Mauricio Delgado and Elizabeth Tricomi argue that to successfully steer decision making, not only does the brain need to register the hedonic aspects of reward or punishment, but it must also exhibit the ability to learn from experience involving reward and punishment, bypass time-consuming and energy-demanding computations, and ignore spurious associations between events and outcomes. They invoke a wealth of experimental findings in making the case that the striatum may be able to process reward-related information in such a way so that it can meet these difficult demands. In the process they offer a rich description of the functional specialization of the various regions of the striatum. Next, John O'Doherty reviews the current state of knowledge about the neural mechanisms that underlie learning about rewards and punishments, differentiating between different types of value signals that are used by humans as a function of task demands. Furthermore, he describes the putative computational mechanisms by which predictive valuation signals might be learned through experience, and reviews evidence for the operation of such mechanisms in the brain. Ending this section, Diego Pizzagalli, Daniel Dillon, Ryan Bogdan, and Avram Holmes review the basic research on the neural correlates of reward and punishment, distinguishing between the functions of the ventral striatum, amygdala, the orbitofrontal cortex, and the anterior cingulate cortex in relation to outcome anticipation and action representation. They then extend this knowledge to a characterization of depression as

abnormal incentive processing. Their chapter shows how knowledge gained about the reward circuitry of the brain can be used to understand underlying mechanisms of psychopathology, and how knowledge learned from studying healthy and disordered populations can be exchanged fruitfully to expand understanding of valuation processes in both populations.

The fourth section of the book entitled *Cooperation and Trust* deals with aspects of choice that are influenced by interpersonal and social norms governing behavior. Alan Sanfey and James Rilling start the section by focusing their chapter on research in the neurosciences that investigates social decision making involving dyadic interactions. They review research on game theory involving several central tasks such as Prisoner's Dilemma games, the Trust Game, and the Ultimatum Game. Their review sheds light on various factors that determine choices in the context of these tasks, including affiliation and trust, competition, and adherence and violation of social norms. This chapter also serves an important auxiliary purpose by highlighting the link between decision neuroscience and the emerging field of neuroeconomics (Glimcher, Camerer, Poldrack, & Fehr, 2009), which more focally deals with factors underlying economic choices in the marketplace. Next, Daniel Houser and Erte Xiao discuss biological and social empirical evidence on motives for punishment. They focus on the effects of punishment on cooperation, delineating conditions under which punishment is likely to be effective and ineffective in fostering cooperation. They then focus on various motives for punishment, including norm expression, egalitarianism (fairness), and emotion expression. Their chapter makes a strong case for role of punishment in interpersonal exchange, and supports it further by bringing biological data to bear on this issue. In combination, the

two chapters in this section present convincing evidence that dyadic and multi-person interactions are strongly influenced by the interaction of multiple systems in the brain, and that understanding choices is also contingent on understanding the social norms that govern action selection.

The fifth and final section of this volume entitled *Goal-directed Decision Making* deals with the contributions of planned and spontaneous cognitive processes to judgment and decision making. As noted earlier, the inclusion of this section was motivated by our desire to highlight the role of judgment and decision making processes in selective higher-order mental activities. In the first chapter, Kalina Christoff, Kamyar Keramatian, and Rachelle Smith argue that although 30% of thoughts that people have can be classified as mind wandering, the contribution of this form of mental activity to cognition has been neglected compared to the contributions of goal-directed mental activity. They examine the neural and cognitive mechanisms that underlie spontaneous thinking, and argue that this form of thought contributes to judgment and decision making by consolidating new memories and the adaptive re-consolidation of old memories in relation to current tasks and emotions. Next, Jorge Moll and Jordan Grafman review the cognitive and computational perspectives on planning, and provide a description of the cognitive components of plan decision making that can be mapped onto the brain. They argue that the crucial components of plan-specific decision making are primarily stored in the prefrontal cortex (PFC) as a component of the plan itself, with plan execution assisted by motor and other processes carried out by the basal ganglia, motor cortex and other cortical regions such as the parietal lobes. The accumulated imaging and neuropsychological evidence strongly suggests that the major representation of plan-level

knowledge in the human brain—including plan-specific decisions—occurs in the PFC, and that specific features of the plans are encoded and stored in subregions within PFC. The book closes with a chapter by Oshin Vartanian on creativity. He argues that the tendency of creativity researchers to study only those processes that are unique to creativity has led to a dearth of attention paid to judgment and decision making processes in creative cognition, a problem that is rectified when creativity is viewed as one of many avenues for solving everyday problems. He presents behavioral and neural evidence to support the important role decision making plays in creativity, especially in relation to selecting solution paths.

Summary

Over the last decade we have witnessed the emergence of progressively more sophisticated biological models of choice. Gaps in knowledge remain. For example, currently we know much less about the neural systems that underlie computation of probability than those that underlie computation of reward (Sanfey, 2007). Nevertheless, the field is moving toward ever more complete mechanistic models of human decision making (O'Doherty & Bossaerts, 2008). In the process, this work is able to offer new and incisive tests of hypotheses derived from behavioral theories of judgment and decision making. It is our hope that this book provides a framework for thinking about some of the key issues in this area, as well as capturing the aspirations of this research program.

References

Damasio, A. R. (1994). *Descartes' error: Emotion, reason, and the human brain*. New York: Grosset/Putnam.

Damasio, A. R., Damasio, H., & Christen, Y. (Eds.).(1996). *Neurobiology of decision-making*. Berlin: Springer-Verlag.

Doya, K. (2008). Modulators of decision making, *Nature Neuroscience, 11*, 410-416.

Evans, J. St. B. T. (2008). Dual processing accounts of reasoning, judgment, and social cognition. *Annual Review of Psychology, 59*, 255-278.

Frank, M. J., Cohen, M. X., Sanfey, A. G. (2009). Multiple systems in decision making: A neurocomputational perspective. *Current Directions in Psychological Science, 18*, 73-77.

Glimcher, P., Camerer, C., Poldrack, R., & Fehr, E. (Eds.).(2009). *Neuroeconomics: Decision making and the brain*. Academic Press: London, UK.

Goel, V. (2007). Anatomy of deductive reasoning. *Trends in Cognitive Sciences, 11*, 435-441.

Goldstein, W. M. & Weber, E. U. (1997). Content and discontent: Indications and implications of domain specificity in preferential decision making. In W. M. Goldstein, & R. M. Hogarth (Eds.), *Research on judgment and decision making* (pp. 566-6 17). Cambridge, UK: Cambridge University Press.

Knutson, B., Taylor, J., Kaufman, M., Peterson, R., & Glover, G. (2005). Distributed neural representation of expected value. *Journal of Neuroscience, 25*, 4806-4812.

Loewenstein, G. F., Weber, E. U., Hsee, C. K., & Welch, N. (2001). Risk as feelings. *Psychological Bulletin, 127*, 267-286.

O'Doherty J. P., & Bossaerts, P. (2008). Toward a mechanistic understanding of human decision making. *Current Directions in Psychological Science, 17*, 119-123.

Sanfey, A. G. (2007). Decision neuroscience: New directions in studies of judgment and decision making. *Current Directions in Psychological Science, 16*, 151-155

Yu, A. J., & Dayan, P. (2005). Uncertainty, neuromodulation, and attention. *Neuron*, 681-92.