Chapter 12

Decision-making Under Risk and Stress: Developing a Testable Model

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Decisions are made throughout our daily life, even though most of the time we are unaware that we make many of those decisions. Changing lanes on the highway, choosing to check email, deciding what to make for dinner, deciding to take aspirin to alleviate a headache are all examples of those daily decisions that seem not to garner much awareness that a decision is involved. The more salient decisions however are those that often involve stress of some kind: a time deadline, a decision with major financial implications, health, or one in which we experience a great amount of subjective uncertainty about a tradeoff. These types of stress though are related to the process of decision-making itself. That is, how we go about deciding (for example, the tradeoffs we make) and the constraints of our decision (including time constraints and budget constraints) can make decision-making subjectively stressful.

Another type of stress arises due to the situation itself, independently of the decision-making that is supposed to take place. This type of stress creates a context in which the effects of stress on decision-making may be different than the effects of stress as defined by time pressure or difficult tradeoffs inherent to decision-making itself. This kind of stress is less specific to decision-making and it is has been studied, modeled and characterized in psychological, physiological and clinical literature (McEwen 2000, de Kloet 2005). Understanding the relation between this type of stress and decision-making can open a new window into a completely new area previously unaddressed by decision-making research. It can help us to understand the psychological and physiological processes that govern compromised or impaired decision-making that often accompanies conditions of severe or pathological stress like bereavement, depression or post-traumatic stress disorder. This brief report addresses relevant research at the intersection of stress and decision-making with the goal of outlining a preliminary model about the underlying neurocircuitry.

Thus while the stress literature has described different components (or types) of stress reactions and there is a strong tradition of research on behavioral decision-making (Broadbent 1971, and Janis and Mann 1977), the study at the intersection of stress and decision-making remains fairly simple in its analysis.

How do different types of stress influence different types of decisions? Does our current understanding of neuroanatomy and neurophysiology provide useful tools in understanding the intersection of stress and decision-making? This brief review carves out a piece of the intersection of stress and decision-making and provides a model for the role neuroscience can play in understanding the interplay. We first review some relevant decision-making models and then review how stress might be involved in decision-making and how it may be incorporated in decision-making models.

Behavioral Decision-making Models

The field of decision-making focuses on three major types of decisions: 1) multiattribute choice, 2) decision-making under risk, and 3) decision-making under uncertainty.

1. Multiattribute choice involves deciding between options where each option has many dimensions. For example, when purchasing a digital camera one may consider price, megapixels, zoom, and storage capacity. Each camera has a value on each of those dimensions and the decision maker's problem is to choose the camera that provides a best fit given the requirements (for example, a camera under $800 that can take pictures of your daughter playing soccer).
2. Decision-making under risk involves deciding between options that offer probabilistic outcomes. For example, the oncologist tells the patient the probabilities of successful outcomes associated with a menu of treatment options and the patient uses those probabilities to decide on a particular course of treatment. In this case the probability is "known" to the decision maker because it was given by the oncologist. Such a known probability is what is meant by "risk" in the decision-making literature. The term risk applies to the case where probabilities are given explicitly and are not necessarily associated with a negative outcome. For example, decision-making under risk applies to contexts even when there are no losses (for example, a choice between receiving $50 for sure and playing a gamble that yields $100 at 50 percent and $10 at 50 percent falls in the domain of decision-making under risk).
3. The third type is called decision-making under uncertainty and refers to cases where the probability is not known as a numerical value. Decision-making under uncertainty includes deciding between options where the probability of the event is described verbally ("highly likely", "more likely than not", "somewhat probable", and so on) or the decision options are described as conditional propositions ("if it rains tomorrow we will do X, otherwise we will do Y", "if the diagnostic test is positive, then we will follow this treatment plan").

To better understand processes involved in decision-making and to be able to predict behavioral choices traditionally, formal mathematical models that accurately predict decision-making outcomes under various conditions had been used. To this end, the underlying mathematical models for the three types of decisions listed above are different: multiattribute choice does not involve probability; decision-making under risk involves probability; and decision-making under uncertainty involves ambiguity about chances or a lack of numerical precision about the associated probabilities. A common element of many such decision-making models involves a weighted representation of some kind. A simple multiattribute choice model defines subjective values on each dimension (such as how much the decider values an extra megabyte in computer RAM or an extra year of life under a particular level of quality of life, values that may not be linear in their variable), weights each of those subjective values with subjective weights that index the importance of each dimension, and takes a weighted sum to evaluate each option. A simple multiattribute choice representation is $\Sigma w_i v_i(x_i)$ for dimension i that has an importance weight w and a transformation v of the original dimension value. The choice mechanism then selects the option with the greatest weighted sum. A classic reference for this model is Keeny (1992).

A standard model for decision-making under risk is prospect theory, which also follows a weighted representation of a special form. A probabilistic prospect is represented as $\Sigma[w(p_{1-i})-w(p_{1-(i-1)})]v(x_i)$. This complicated form allows for proper summation with nonlinear weights on the probabilities. The logic of this representation is that each outcome is transformed to its subjective value, weighted by the marginal cumulative transformed weight, and summed across outcomes. The option with the greatest cumulative weighted sum is selected. Particular functional forms for weighting function w and value function v have been proposed, but for our purposes we focus on the qualitative aspects of w and v. Behavioral data suggest that in the case of probabilities that are explicitly given, people place more weight on small probabilities and less weight on large probabilities in a manner that leads to an inverse S-shape transformation (concave for small p, convex for large p). Further, behavioral data suggests that value is defined with respect to changes from a reference point, and thus the value function v is defined with respect to gains and losses. This is perhaps the most important addition prospect theory made to the generalized expected utility framework. An important behavioral observation is that in many domains, losses receive more weight than gains. These two properties of w and v can account for two broad classes of behavioral decision-making results. The weighting function w can account for observations of risk aversion and risk seeking; the value function v can account for the behavioral observation that "losses loom larger than gains." Two classic references in this behavioral decision-making tradition are Kahneman and Tversky (1979) and Tverksy and Kahneman (1992), research that lead to a Nobel prize in Economics.

The third type of decision-making model, decision-making under uncertainty, has received relatively little attention. This form of decision-making model also follows a weighted sum representation, but is even more complicated than the representation outlined above for decision-making under risk because it involves a further mapping from the characterization of an event into its subjective probability. For references in the behavioral decision-making tradition see Fox and Tversky (1998) and Wu and Gonzalez (1999).

A major limitation of the behavioral decision-making tradition is that it tends to be descriptive in the sense that mathematical models are developed to account for properties of the data. In some cases the mathematical model is predictive of new empirical results and in this sense the research program has been successful (Wu and Gonzalez 1996), but a justifiable critique of this literature is that it is not constrained nor is it based on fundamental psychological or neuroscience principles that govern psychological and brain processes that are at the base of the decision-making process. This is most clearly seen in the partition of decision-making problems into three types (as reviewed above—multiattribute choice, decision-making under risk and decision-making under uncertainty). This partition follows not from psychological principles but mostly because of mathematical convenience in the development of the decision representation (different types of weighted sums depending on whether the problem involves probability, does not involve probability or involves uncertainty). This modeling bias makes it very difficult, however, to develop a better understanding of the various psychological or physiological variables that may be influencing the decision-making process under various circumstances.

Future progress in the field of decision-making is dependent therefore on the ability to decompose the process of making a decision into testable cognitive and affective components mediated by the dedicated underlying neurocircuitry. This necessarily will have to incorporate vast literature in cognitive science, social psychology, cognitive and affective neuroscience. This next step is especially important for the development of models for decision-making and stress, as it will have to link up large bodies of existing research—critical for future progress. It is unlikely for example that stress is implicated differently in a decision-making problem involving choice of nonprobabilistic outcomes, probabilistic outcomes or uncertain outcomes, the three major partitions of the decision-making literature. A deeper understanding of the role of stress in decision-making will emerge when we reconceptualize decision-making in terms of its cognitive and affective components, and when we provide a psychological, physiological and neuroanatomical foundation for behavioral concepts such as risk aversion and loss aversion.

In the last decade, a new and exciting program of research under the domain of neuroeconomics involving neuroimaging of decision-making processes has emerged, suggesting that mapping of some of the relevant mathematical/behavioral variables from the models described above onto the neuroanatomical substrate might be possible. Early studies provided some promising initial evidence that the behavioral concepts of the weighting and value functions might have meaningful neural correlates. The transformation of probabilities characterized by the

weighting function have been associated with neural activation in the dorsolateral prefrontal cortex (Tobler et al. 2008), the ventral striatum (Hsu et al. 2009) and dorsal anterior cingulate cortex (Paulus et al. 2006). The behavioral concept of loss aversion has been linked to activity in the ventromedial prefrontal cortex and ventral striatum (Tom et al. 2007). These early studies use different paradigms of decision-making and it is not surprising that the findings reported in one study are not necessarily replicated in the others. However, they do provide critical data for initial neuroanatomical models of decision-making and further work is obviously required to replicate, reconcile and confirm these initial findings. This work is clearly in its early stages and much more research is needed to establish the functional neurocircuitry of decision-making and to understand the implications and boundary conditions.

Intersection of Decision-making and Stress

Much of the research in the behavioral decision-making tradition focuses on the subjective experience of stress. In experimental research this has been typically operationalized as a manipulation of time constraints, or of performance demands (Broadbent 1971). Stress in decision-making can arise because of external factors such as time constraints placed by the demands of the decision, or internal factors such as a decision involving a difficult tradeoff between several important dimensions (for example, some end-of-life decisions). Here the stressor is internal because the tradeoff itself is experienced as "stressful" or that the decision itself produces "subjective distress." These kinds of external and internal forms of stress undoubtedly influence decision-making, as many classic examples from the psychological decision-making literature show (Broadbent 1971, and Janis and Mann 1977). The kinds of variables that characterize much of this literature though focus on more behavioral aspects of distress and behavioral aspects of decisions; however, these kinds of stress conditions may play out differently than the environmental/physiological stress or traumatic stress that is antecedent to post-traumatic stress disorder (PTSD). Understanding the implications of severe situational, physiologic or traumatic stress on decision-making is critical however, if one aims to understand decision-making under extreme conditions or the interplay between stress-related psychopathology and decision-making.

To begin addressing these questions it is important to focus on stress concepts that are concretely defined in a way that have a biological component, for example, stress that activates the limbic-hypothalamo-pituitary-adrenal (LHPA) axis (Shin and Liberzon *in press*). Until recently there has not been much research attention given to forms of stress that activate the LHPA axis in the context of decision-making. Two recent studies examined decision-making under risk using a Trier Social Stress Test, which is designed to elicit robust LHPA response through an anticipated public speaking task. Preston et al. (2007) used the Iowa Gambling Task and Starcke et al. (2008) used the Game of Dice Task (GDT) as their respective decision-making tasks.

Both studies yielded similar results, suggesting that anticipatory stress leads to more disadvantageous results, except that Preston et al. found an interaction with gender but Starcke et al. did not, despite different decision-making tasks. These early studies are important because they manipulated stress level and measured physiological correlates of it, however they did not attempt to delineate effects of stress on formal behavioral parameters or the psychological process involved in decision-making. In line with our earlier recommendation of decomposing decision processes into a set of cognitive and affective processes, Starcke et al (2008) provide evidence that the stress manipulation did not influence the executive functioning part of the GDT, which provides a useful boundary condition in our understanding of the role of stress on decision-making.

One interesting feature of both the Preston et al. (2007) and Starcke et al. (2008) studies is that they examined the role of learning probabilities over repeated trials and the role of feedback. Much of the behavioral decision-making literature has focused exclusively on the actual decision under cases of known probability (risk), and not on learning and feedback over repeated trials. It is possible that stress influences such processes in very deep ways, and a complete understanding of the role of stress on decision-making should examine other variables such as learning. Further, both Preston et al. (2007) and Starcke et al. (2008) manipulated stress in manner that has been previously shown to activate the LHPA axis (Trier task), and Starcke et al. also included a manipulation check using salivary cortisol. A slightly different paradigm was used by Porcelli and Delgado (2009), who demonstrate that stress as manipulated through a cold pressor task (and verified with skin conductance) can exacerbate the reflection effect commonly observed in the behavioral literature (risk aversion in gain-only gambles and risk seeking in loss-only gambles). However, to our knowledge there does not exist to date published research that manipulates cortisol directly.

Recently our research group developed a paradigm involving an oral administration of hydrocortisone (synthetic cortisol analogue) during a gambling task to begin addressing the direct effects of elevated stress hormones on decision-making processes. Using a gambling paradigm that manipulates both the value and probabilities of the options in an orthogonal design and using gain, losses and mixed gambles, we find behavioral evidence for the usual weighting function and value function properties of probability transformation and loss aversion, respectively. These properties are interestingly moderated by a single dose hydrocortisone administration (confirmed by saliva cortisol levels) that is given in a double-blind placebo control fashion, and is not detectable by the subjects beyond chance level. Furthermore, our paradigm allows us to begin outlining the neurocircuitry underlying different parameters of decision-making process, described by the mathematical models, such as loss aversion, probability assessment and weighing function in the same subjects and the same conditions, allowing a clearer description of the neurocircuitry involved. Finally, the hydrocortisone

administration modulated the activity in the same brain region associated with the parameters listed above in a manner that is entirely consistent with the behavioral effects observed, allowing us to test specific mediation models.

Our preliminary findings in concert with the reported results in the literature using the Trier task suggest that cortisol sensitizes reward processing and at the same time appears to blunt the processing of probability. These initial conclusions of course, require much more research before they are planted firmly in the literature. However, we view them as providing an extremely promising direction for a better understanding of the role of stress on decision-making, in a paradigm linking the underlying cognitive and affective processing with associated neural circuitry. The results suggest that despite our critique that the behavioral decision-making literature has not been founded on first principles, there might be evidence that two major properties identified by the behavioral work, the weighting function w and the value function v, might be subserved by two separate neuroanatomical systems. The study of the role of stress on decision-making promises to be an active area of research that can provide many deep clues to decision-making in health, under extreme stress and during disease process.

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Chapter 13

Brain Processes During Expert Cognitive-Motor Performance: The Impact of Mental Stress and Emotion Regulation

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Overview

The Soldier of the twentyfirst century will face unprecedented challenges regardir information management, decision-making, and adaptive motor responses on tl battlefield critical to both mission success and survival. This scenario is based c the premise that the United States armed forces currently possess and will likel continue to acquire the most advanced technologies ever developed for use i the history of warfare. Such technological advancement will place a premium o the human operator's (specifically, the Soldier's) functional attention capacit in order to realize the advantages and exploit the limits of these technologie: The elicitation of intense emotional states and experience of uncontrolled arous under battle conditions can consume, undermine, and degrade the critical ment resources and processes that future force warriors will require to execute thei responsibilities. Therefore, the understanding and promotion of effective ment states, achieved through effective training programs and emotion regulation, wil help the Soldier to manage arousal, preserve attentional capacity, and focus whil employing such sophisticated, but attention-demanding technologies while "unde fire." Such mental states may also confer resilience to the long-term consequence of stress such as post-traumatic stress disorder (PTSD). The recognition of th essential role that mental processes play in the effectiveness and wellbeing o military personnel has recently been formalized in the Army's initiative concernin the Human Dimension. This initiative represents a new development beyond th traditional human factors perspective of operator effectiveness in interaction wit technology and equipment. This new element of personnel training explicitl addresses the ethical/moral, social, psychological/cognitive, and physica training elements of the Soldier's preparation as a focus complementary to th advancement of technology. This program, which was initiated in the fall of 200 by Training and Doctorine Command (TRADOC), was described in one of the featured sessions in the second annual conference on "Sustaining Performance