INTERACTIONS BETWEEN ACUTE STRESS AND FINANCIAL DECISION-MAKING

By Anthony J. Porcelli

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and approved by

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Day-to-day decision-making is susceptible to various demands exerted by the environment. At times, such demands can lead to stressful conditions, affecting both psychological and physiological states. In order for researchers to understand how to control stressful conditions while making informed goal-oriented decisions, a necessary first step is to probe the interaction between the state created by exposure to acute stress and how decisions are performed under those conditions. To that end, the goal of this dissertation is to elucidate the effects of acute stress on decision-making at both the behavioral and neural levels. This will be accomplished by focusing on three aspects of the relationship between stress and decision-making. First, the question of how acute stress alters financial decisions during a financial decision-making task similar to those used in the fields of neuroeconomics will be addressed. The second will be an examination of whether or not the effects of acute stress generalize to other types of more automatized decision-making tasks – in this case, a task involving instrumental conditioning. Finally, the neural systems underlying the potential interaction between acute stress and financial decision-making will be considered.

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GLOSSARY OF ACRONYMS

Analysis of Variance (ANOVA)

Anterior Cingulate Cortex (ACC)

Behavioral Inhibition Scale (BIS)

Blood-oxygen-level-dependent (BOLD)

Expected Utility (EU)

Functional Magnetic Resonance Imaging (fMRI)

General Adaptation Syndrome (GAS)

General Linear Model (GLM)

Hypothalamic-Pituitary-Adrenal Axis (HPA)

Medial Prefrontal Cortex (mPFC)

Orbitofrontal Cortex (OFC)

Prefrontal cortex (PFC)

Prospect Theory (PT)

Region of Interest (ROI)

Skin Conductance Levels (SCL)

Ventrolateral Prefrontal Cortex (VLPFC)

Working Memory (WM)

Chapter 1

Introduction

The fields of economics and psychology have long studied the manner in which human beings make decisions, often reaching contradictory experimentally derived conclusions. Recent advances in neuroscience have begun to bridge the gap between these two disciplines by revealing the underlying neural architecture supporting decision-making. The emerging field of neuroeconomics provides a different standard by which the findings of both fields can be evaluated, yielding insights into the process of decision-making by clarifying the relationship between the diverse neural areas involved in its execution. The ability to make decisions, however, can be influenced and distorted in any number of ways. One prime example is decision-making under stress.

Study of the relationship between stress and decision-making is vitally important in a modern society where people must make life-and-death decisions under stress on a daily basis, as in the case of soldiers in battle for instance. Soldiers, however, are far from the only people whose decision-making abilities can be affected by such factors. Acute stress has also been studied in other demanding workplace environments, such as in the context of emergency medical services (e.g., Kozena & Frantik, 2001). Even ordinary citizens are bombarded outside of the workplace with terrifying information in the form of worrisome headlines and newscasts which, combined with 'normal' life stress factors related to one's work or interactions with other people, may lead people to make less rational decisions. By gaining a greater understanding of how stress interacts with decision-making, it may be possible to develop interventions that would prevent stress-related degradations – or enhance stress-related improvements – to this vital faculty.

1.1 The History of the Concept of Stress

Before the physiological effects of stress could be clearly defined, it was necessary for noted physiologist Walter Cannon to identify the role of homeostasis in an organism's ability to adapt to its environment (Cannon, 1932). Homeostasis, as conceptualized by Bard, is an organism's ability to maintain equilibrium among its own bodily functions – resulting in a relatively constant internal environment. For example, homeostatic functions regulate the balance of water within the body in addition to the circadian rhythm of the sleep/wake cycle. Maintenance of homeostasis is the result of a complex interaction of peripheral and central nervous system, as well as endocrine system, activity. Because homeostatic functions are intimately related to the endocrine system, and the effects of stress are strongly manifested at that level, it was vital that this concept be clearly defined to properly understand the manner in which stress interacts with an organism's physiology.

Despite a coordinated effort on the part of the nervous and endocrine systems, homeostasis is maintained through a delicate balance that may be easily upset. Such an upset occurs when an organism is exposed to a perceived threat, which Cannon described as the "fight-or-flight response" (Cannon, 1915). This response is characterized by stimulation of the sympathetic branch of the autonomic nervous system (resulting in increased heart rate, blood pressure, hormonal discharge, and other increases in physiological activity), thus freeing bodily resources to allow the organism to act quickly in the face of danger (Cannon, 1932). It is helpful to think of the stress response in these terms. Excitatory sympathetic nervous system activation occurs during stress exposure, while subsequent inhibitory parasympathetic nervous system activation attempts to bring

this heightened physiological activity back to baseline – in effect reestablishing homeostasis. Under increased exposure to stress, however, this interaction may become disregulated.

Famed endocrinologist Hans Selye was the first to conceptualize the impact of stress on physiology, in addition to devising the term itself. Prior to Selye's groundbreaking research, the wide constellation of symptoms typical of the stress response (both physiological and psychological) were viewed as unrelated occurrences. The situations under which this response can be observed are often dissimilar, and therefore cannot be causally linked. According to Selye's definition, "stress is the nonspecific (that is, common) result of any demand upon the body, be the effect mental or somatic" (Selye, 1993). By defining stress in this manner, Selye linked the stereotyped response resulting from any number of disparate phenomena under the broad heading of "stress". It is important to note, however, that stress may be also defined in terms of the stimuli that evoke these physiological and psychological responses.

1.2 Categories of Stressors

Diverse stimuli (broadly defined as stressors) can trigger the cascade of physiological changes that will be described below, especially when the cognitive and affective faculties of human beings become a factor. Stressors may be either processive or systemic (for a review, see Herman & Cullinan, 1997). A processive stressor is a stimulus in the environment that may be interpreted by the organism as a potential danger, but does not directly threaten the organism's (physiological) homeostasis. For example, in humans the act of giving a public speech and other psychosocial stressors are

processive. After being processed by the cerebral cortex of an organism, hence the term 'processive', stress-related information is transmitted to the hypothalamus – which activates the autonomic nervous system. Consequently, there is a great deal of variability between individuals with regards to exactly what will function as a stressor of this type. Systemic stressors, on the other hand, pose an immediate physiologic threat that directly interferes with an organism's homeostatic functions. Examples of systemic stressors are bodily injury or trauma, or exposure to noxious stimuli (such as extreme cold). These are, of course, only examples of the wide range of situationally specific factors known to induce the stress response.

Interestingly, the brain regions underlying stress reactions caused by processive and systemic stressors are partially dissociable. Research indicates that processive stressors, given their more cerebral nature, engage both subcortical and cortical brain regions (Herman & Cullinan, 1997). While this neural circuitry will be discussed in more detail in Chapter 4, suffice it to say that the physiologic effects of processive stressors result from a complex interaction between limbic and frontal brain regions, and the hypothalamus. In contrast, systemic stressors do not engage limbic regions to the same degree (Herman & Cullinan, 1997). It has been postulated that this relates to the fact that systemic stress is immediately relevant to the survival of the stressed organism, necessitating a more direct connection to brain regions that control the stress response (i.e., the hypothalamus) from lower-level regions such as the brainstem.

1.3 Peripheral Physiological Correlates of the Stress Response

Selye theorized that both humans and animals have the ability to adapt to environmental stimuli via specific physiological pathways of the type just described, and that such adaptations exact a toll on the body and mind despite their importance for the survival of an organism. In time, Selye characterized the stress response itself as a syndrome: *biologic stress syndrome* or General Adaptation Syndrome (GAS). GAS remains useful tool in understanding the interaction between stressful stimuli and homeostatic physiological processes within the brain and body. The syndrome can be divided into three stages: alarm, resistance, and exhaustion.

During initial exposure to a stressor an organism undergoes the alarm or "fight-or-flight" response as the systems of its body become hyperactive in order to adaptively deal with the noxious element in its environment**.** Early on Selye observed specific and interdependent changes in the physiology of rats representative of this stage: enlarged adrenal glands, increased production of adrenaline, shrinkage of lymphatic structures, and gastrointestinal ulcers (Selye, 1993). During alarm the organism's body will exhibit increased blood flow and break down its own tissues for increased energy production. It is during this stage that the aforementioned increases in sympathetic nervous system activity occur. Even in the continued presence of a stressor such a state of hyperactivity cannot be maintained over time, and the subsequent stage of resistance ensues.

Effects observed during the resistance phase are nearly the opposite of those exhibited during alarm, including dilution of the blood and construction of bodily tissues. This stage is generally a state of energy conservation balancing the energy consumption that had occurred during the alarm reaction. During resistance, the parasympathetic

branch of the autonomic nervous system activates in an attempt to bring hyperactive functions back to baseline by inhibiting sympathetic activity. When an organism is exposed to a stressor over an extended period of time (or to one of sufficient intensity) it experiences the stage of exhaustion. At this point the body has reached the limit of its ability to adapt, having overextended itself (Selye, 1993). If the stressor persists, and is noxious enough, further depletion of bodily resources and even death can occur.

Due to the broad range of peripheral effects of stress described above, it is possible to non-invasively measure the stress response via its effect on the body at multiple levels. One notable advantage yielded by this aspect of the body's response to stress is that said measurements may be taken concurrently. Because of the sympathetic nervous system component of the stress response, measures of blood pressure, heart rate, and heart rate variability are useful (Vrijkotte, van Doornen, & de Geus, 2000). In addition, alterations in sympathetic activity are known to influence skin conductance (measurements of the electrical resistance of the skin; Lang, Davis, & Ohman, 2000). Consequently, such measurements are a useful technique for monitoring stress levels. Finally, endocrine system involvement in the stress response allows for the measurement of specific hormones in the saliva or blood plasma, primarily cortisol in humans.

Based on this extensive understanding of the physiological effects of stress, it is apparent that the degree to which an organism is exposed to a stressor may result in physiologic adaptations that can be characterized as acute or chronic. This ability to adapt is a limited resource, known as allostasis (McEwen, 2003). Brief exposure to a stressful stimulus is considered to be acutely stressful, resulting in non-permanent physiological changes. Repeated or long-term exposure to a stressor, on the other hand,

constitutes chronic stress. For example, brief exposure to extremely cold temperatures acutely results in a number of energizing physiological changes that enable an organism take action to deal with or avoid the source of the stress (e.g., increased heart rate and blood pressure). If exposure to the cold persisted a state of chronic stress would eventually ensue, involving depletion of bodily resources and possibly permanent damage. Efficient adaptation at that point is no longer possible, resulting in the impairment of a number of vital processes – one example being the immune system (McEwen, 2003). Consequently, over the lifespan of an organism the wear and tear of an increased allostatic load results in decreased adaptability to future alarming stimuli as well as increased vulnerability to disease (McEwen, 2003).

It is worthwhile to note that characterization of the ability to adapt to stress as a limited resource runs parallel to an extensively researched topic in the social psychological literature. Specifically, it has been observed that executive processes (e.g., choice and self-regulation) may be fueled by some common resource. Exerting oneself to accomplish such functions can result in the phenomenon of ego or resource depletion – whereby prior volitional acts cause decrements to similar behaviors in the near future (Baumeister, Bratslavsky, Muraven, & Tice, 1998). While exact nature of this resource has not yet been defined, an understanding of the manner in which stress depletes bodily resources could provide a vital link between such theories and the basic physiological and neurochemical processes involved in that phenomenon.

1.4 Central Nervous System Correlates of the Stress Response

Advances over the last century have uncovered a great deal of information about neural pathways and neurochemicals involved in the stress response. In humans, excitation of the hypothalamus due to extended stress exposure causes the release corticotrophic releasing factor. This causes the pituitary gland to discharge adrenocorticotrophic hormone into the bloodstream. Upon reaching the adrenal cortex of the adrenal glands, glucocorticoids (e.g., cortisol in humans) are released into the bloodstream (Selye, 1993). Thus the "hypothalamic-pituitary-adrenocortical" (HPA) axis leads to glucocorticoid hypersecretion under stress, which in turn engages in a negative feedback loop inhibiting hypothalamic and pituitary activity. This action ensures that sympathetic nervous system activity resulting from HPA activation will not run rampant.

These stress hormones exert global effects on the brain and body and also affect mental states (Herman et al., 2003). Research from multiple sources indicates that increases in glucocorticoid levels exert a profound influence over prefrontal cortex (PFC) structure and functioning, in both animals and non-human primates. For example, corticosterone (the central cortisol analogue in rodents) has been associated with a reorganization of PFC dendritic fibers in rats (Wellman, 2001). Additionally, injections of hydrocortisone (a synthetic form of cortisol) have been linked to impairment of medial prefrontal cortex based behavioral inhibitory capabilities in non-human primates (Lyons, Lopez, Yang, & Schatzberg, 2000). By impairing PFC function, excessive levels of cortisol appear to disinhibit HPA activation even further – increasing sympathetic nervous system activity even more.

Both human and animal research support the existence of anatomic and neurochemical relationships between subcortical structures that respond to stress, and PFC. For example, rodent medial PFC is one target of the stress-related neurochemical response (Brown, Henning, & Wellman, 2005) via connections with the basolateral amygdala (McGaugh & Roozendaal, 2002). Lesions within these amygdalo-PFC pathways have been shown to attenuate catecholamine release within PFC in primates (Goldstein, Rasmusson, Bunney, & Roth, 1996). In addition, it has been observed that stress and subsequent increases in glucocorticoid levels are associated with increased dopamine release mesolimbic reward areas, such as the nucleus accumbens in the ventral striatum (Wand et al., 2007).

1.5 Stress and Cognition Interactions: Working Memory Example

As previously outlined, engagement of the stress response initially results in increased arousal via activation of the sympathetic branch of the autonomic nervous system. Although excessive arousal can result in poorer performance on some cognitive tasks, a more moderate level of arousal can be associated with performance improvements. This observation can be traced back to the famous Yerkes-Dodson law (Yerkes & Dodson, 1908). It posits that an inverted U-shaped relationship exists between performance and arousal, such that inadequate or excessive levels of arousal result in poorer performance while some mid-level of arousal optimizes task performance. Furthermore, this pattern of behavior injects a great deal of individual variability into individuals' responses to stressors because what is perceived as "too little" or "too much" stress can vary greatly from person to person.

As previously discussed, ample evidence exists in support of reciprocal relationships between subcortical areas that respond to stress and cortical regions known to subserve various aspects of cognition. Therefore, although it is possible that stress exerts a global effect on cognition as a whole it is equally plausible that stress has a differential impact on various cognitive faculties – especially those that depend on coordinated interactions between cortical and subcortical brain regions. Yet, these conclusions are not mutually exclusive. It may be that excessive levels of stress impair higher level cognition (as in the case of working memory described below), but leave lower level mechanisms (such as those involved in conditioning) unimpaired – or even enhanced (Shors, Weiss, & Thompson, 1992). Thus, whether an impairment or enhancement of performance is observed largely depends on the type of task a stressed organism is engaged in.

A great deal of research has examined the effects of stress on a specific form of cognition – working memory (WM), which may be defined as the retention and/or manipulation of to-be-remembered information over brief time intervals. This faculty is believed to underlie many higher cognitive processes essential to the decision-making process (Baddeley, 1996) including reasoning (Prabhakaran, Rypma, & Gabrieli, 2001), planning (Goel & Grafman, 1995), and problem solving (Duncan et al., 2000). Studies that have examined the effects of acute stress on WM have produced mixed results. Some have indicated negative effects of acute stress on WM task performance (Kuhlmann, Piel, & Wolf, 2005; Oei, Everaerd, Elzinga, van Well, & Bermond, 2006; Patil, Apfelbaum, & Zacny, 1995). Other studies however have shown such effects in the context of executive tasks, but not for those involving verbal or spatial WM (e.g., McMorris et al., 2006).

Empirical discrepancies of this type have been difficult to reconcile because, across studies, a variety of stress manipulations and WM measures have been used. It may be possible, however, to tease apart the relative impact of different stress manipulations by more directly examining stress-related alterations in neural activity using neuroimaging techniques.

Research indicates that the PFC is a vital neural substrate for WM functions (Curtis & D'Esposito, 2003). Stress-related catecholaminergic changes may affect PFC-based WM processes in primates. In one study, monkeys performed a spatial delayed-response task with varying delay intervals (Arnsten & Goldman-Rakic, 1998). On some occasions, WM performance followed sustained exposure to acutely stressful loud noises (100-110db wide-band frequency). Noise-related performance decrements were greater with longer delay intervals. Performance decrements were attributed to a "hyperdopaminergic" stress response in PFC because the behavioral stress response was mediated by administration of dopamine-receptor antagonists. As WM processes are vital for the maintenance of rational and goal-oriented decision-making, and because the neural correlates of both WM and decision-making share functional and effective connections with similar neural regions, it is plausible that the effects of acute stress on decision-making processes at the neural level might also be influenced by stress-related alterations in PFC functioning.

1.6 Models of Decision-making

Prior to moving on to the research to be discussed in this manuscript, it is important to detail a rich economics literature upon which the behavioral tasks are based.

Rational-choice models based on game-theory research and economics' subjective-expected utility theory are effective tools in the study of decision-making (Janis, 1993). Yet they assume that a decision-maker rationally considers all possible courses of action, and conducts a cost-benefit analysis through a sort of intuitive probabilistic calculus. Under these models action is only initiated after this process is completed. Economic models of decision-making, such as Expected Utility (EU) theory, predict that decision-makers always choose from alternatives by maximizing *utility* – a mental computation combining the reward value of a decision's outcome and its probability of actually coming to pass (Sanfey, Loewenstein, McClure, & Cohen, 2006). This requires that an individual be able to predict a value associated with the outcome of decisions, in addition to the probability that said outcome will come to pass, via some mental computation. The neural bases of such computations will be discussed in Chapter 4.

Although conceptualization of a decision's relative worth to an individual in the form of utility has been immeasurably useful in decision-making research, descriptive theories emerging from the EU model cannot explain discrepancies between its predictions and actually observed behavior (Janis, 1993). An example of this is found in research using a decision task known as the Ultimatum Game, which offers insight into trust and cooperation between individuals (Sanfey et al., 2006). During this task, participants must accept or reject a monetary offer made by a partner who is responsible for dividing the money. If the offer is rejected, neither participant receives anything. According to EU theory the proper decision would be to accept all non-zero offers regardless of the amount, because to do otherwise would not maximize the reward gained by the individual. However, roughly half of all 'unfair' offers are rejected – denoting an

inherent irrationality in the decision-making process (Sanfey et al., 2006). This is expressly inconsistent with EU models.

Thus, it is evident that the performance of human beings does not always conform to the predictions made by some economic models. Others, however, may be more parsimonious with the reality of human decision-making. Prospect Theory (PT; Kahneman & Tversky, 1979) is one model that offers an explanation for the relative irrationality of human decision-makers faced with certain types of choices, by proposing that risk-taking changes based on the framing of a given decision. This proposal, referred to as the framing effect, states that the phrasing of a question can have a powerful impact on subsequent decisions. When presented with two mathematically equivalent decisions, one framed as a possible gain and the other framed as a possible loss, research indicates that individuals exhibit a clear decision-making bias. More specifically, people tend to be risk-averse when a decision is framed as a possible gain, but become risk-seeking when decisions are framed as a possible loss (Laury & Holt, 2005). This robust phenomenon is known as the reflection effect (Kahneman & Tversky, 1979).

Recent research indicates that PT effects, such as framing and reflection, may be influenced by affective processing. One study examined the influence of managers' affective reactions on their risk-taking tendencies while making budgeting decisions (Moreno, Kida, & Smith, 2002). It was observed that, while managers exhibited a typical reflection effect in their choice behavior in the absence of specific affective reactions, this pattern was altered when affect was a factor. Specifically, managers' experiencing an affective state were more likely to show a reversal of the reflection effect (i.e., risk-taking choices in the gain domain and risk-averse choices in the loss domain) while making

decisions that elicited positive versus negative affective states. Earlier research supports the proposal that affect can directly modulate the presence of PT effects in decision-making, one example being a study which observed that participants experiencing positive affect perceived losses more negatively (Isen, Ashby, & Nygren, 1988). It may also be the case that anticipation of a future affective state resulting from a given decision can influence the choice ultimately made (Mellers, 1999), and that such anticipatory reactions in response to risky decisions exert a particularly potent influence (Rottenstreich & Hsee, 2001). Thus, affect itself may modulate the manifestation of PT effects in decision-making.

It may be that the behavioral tendencies associated with PT, and affective modulation of those tendencies, are largely automatized – constituting heuristics in the sense of simple rules "used to assess probability and to predict values" leading to biases in behavior (Tversky & Kahneman, 1974). In compliment, a second proposal states that decision-making might best be characterized by a dual-process approach. Kahneman & Frederick (2002) posit that a dichotomy exists between an intuitive, automatic and effortless type of decision-making (system 1), and a more deliberate, flexible and resource-dependent type of reasoning involving deliberation and evaluation of information (system 2). Furthermore, this theory is concordant with an extensive literature on the topic of automatic and controlled processing originating in the work of Shiffrin and Schneider (1977a, 1977b).

While a dual process interpretation is certainly not novel, and in fact can be traced back to Aristotle and beyond, what is new is a growing understanding of the neural basis of that division. In essence, extensive research across a range of disciplines converges to

suggest that automatized (system 1) behaviors originate in subcortical parts of the brain that are evolutionarily older – and shared with other animals (Evans, 2003). On the other hand, the ability to reason logically may find its origin in more recently evolved frontal brain regions that manifest fully only in humans (Evans, 2003). Furthermore, research on controlled and automatic processing supports the hypothesis that a distributed network of brain regions is involved in automatized versus deliberative behaviors, with subcortical and posterior brain regions largely subserving the former and prefrontal regions the latter (Schneider & Chein, 2003). It should be noted, however, this viewpoint does have its detractors – who make strong arguments in favor of a single system model (for a review, see Osman, 2004). Although this healthy debate is still ongoing, this dissertation adopts a dual process framework for its utility in hypothesis generation and interpretation of empirical results.

Conclusion

The predictions established by PT, in the form of the reflection effect, and a dual process interpretation of decision-making provide excellent platforms for hypothesis generation regarding the effects of stress on decision-making – leading to the following hypothesis as a model for that interaction. A dual-process approach would suggest that stressful conditions that interfere with rational and deliberative processes ought to cause decision-makers to fall back on more intuitive, automatic processes – exacerbating PT-related biases such as reflection effects (e.g., Evans, 2003; Kahneman & Frederick, 2002; Reyna, 2004). This is because, if stress is of a sufficient intensity to impair the frontally based cognitive faculties of logic and reason (system 2), it may promote the use of more

automatic (system 1) processes. If higher-level cognition is impaired in this way, individuals could then fall back on more automatized behaviors to maintain a semblance organized and goal-directed behavior under stress. Whether this would have a positive (or negative) impact on the final outcomes of decisions would depend on the appropriateness of the system being utilized for the task at hand. In this dissertation, the experimental tasks were designed to correspond with automatic or system 1 processes (Chapter 3) as well as deliberative or system 2 processes (Chapters 2 & 4).

The goal of the current research was to examine the effects of acute stress on decision-making. While various stressors were available (e.g., systemic, processive), a single type of stressor was utilized throughout the research to contain this potential experimental variable. Specifically, the studies described in this manuscript involve acute systemic stress, in the form of the well-documented cold pressor task (e.g., Ferracuti, Seri, Mattia, & Cruccu, 1994; Loyke, 1995; Patil et al., 1995). A number of factors led to the choice of this stressor in particular. Firstly, the evidence already discussed that systemic and processive stressors are dissociable at the behavioral and neural level. Secondly because the effects of processive stressors between individuals are highly variable (Wolf, Schommer, Hellhammer, McEwen, & Kirchbaum, 2001), and financial decision-making tasks also show a high degree of inter-subject variability (Laury & Holt, 2005), the best choice of stressor as a foundation for this initial research on stress and decision-making interactions was a systemic one. Finally, as processive stressors engage frontal brain regions also involved in decision-making it seemed sensible to first examine the impact of this more 'basic' form of stress on higher cognition. Having established that basic foundation, it would then be possible in future

research to consider modulation of decision-making by the more complicated class of processive stressors. Therefore, all mention of stress in the remainder of this manuscript should be interpreted as referring to acute systemic stress administered via cold pressor.

In Chapter 2, experiments examining the impact of acute stress on participants' choice behavior in a financial decision-making task will be presented (Experiments 1, 2, and 3). Evidence will be presented suggesting that acute stress modulates risk-taking at the level of the reflection effect, resulting in increased reliance on that heuristic. Having established the effects of stress on this type of decision-making, Chapter 3 will present an experiment aimed at examining whether or not this effect generalizes to more basic decisions involving instrumental conditioning. Finally, in Chapter 4 an fMRI experiment investigating the neural systems underlying stress and decision-making interactions will be discussed. Chapter 5 will conclude the dissertation with a general discussion.

Chapter 2

Behavioral Studies on Stress and Decision-making Interactions

General Introduction

Classical decision-making theory (i.e. EU theory) tends to model the perfectly rational decision-maker – one who is able to employ a mental calculus that will result in an optimal decision given perfect information. PT and a dual process interpretation of decision-making (See Chapter 1) offer explanations for the relative irrationality of human decision-makers faced with certain types of choices, by proposing that risk-taking changes based on the domain of a given decision (Kahneman & Tversky, 1979). This proposal, referred to as the reflection effect, posits that people tend to be risk-averse when a decision is in the gain domain, whereas decisions in the loss domain result in more risk-seeking behaviors (Laury & Holt, 2005). One remaining question, however, is how such domain-dependent risk-taking biases might be affected by demands exerted by the environment during decision-making on a day-to-day basis. Three experiments were designed to address this question. Experiment 1 examines the impact of such demands, specifically stress, on the behavioral tendencies associated with the reflection effect within the loss and gain domains separately. Experiments 2 and 3 examine the possibility of a practice effect confounding the results of Experiment 1.

2.1 Experiment 1: Stress Modulates Risk-taking in Financial Decision-making

2.1.1 Introduction

People are often forced to make important decisions in environments under various pressures that may elicit a stressful response (Janis, 1993). Examples of this fact

abound in lives of decision-makers. Brokers working on the stock market floor, for instance, make decisions involving large sums of money under extreme time constraints while also experiencing excessive noise, heat, and antagonistic interpersonal interactions. In another context, emergency service personnel must make life-saving decisions and perform drug-dose calculations – often under equally exacting conditions (Kozena & Frantik, 2001). Finally, evidence exists that stress contributes significantly to the maladaptive decisions of relapsing drug-abusers who begin using drugs again after prolonged abstinence (Weiss et al., 2001). Examining how stress interacts with decision-making can further clarify why and how such decisions are made under stressful conditions.

If we are to explain how people make informed goal-oriented decisions on a day-to-day basis while concurrently under stress, or how exposure to stress might result in decision-making decrements or improvements, the first step is to clarify the nature of the interaction between stress and decision-making itself. One question is whether or not acutely stressful conditions can lead individuals to become more impulsive and/or risk-seeking in their decision-making behaviors. What is the influence of acute stress on subsequent financial decision-making? In addition, might stress impact decision-making differently when the valence of a decision is manipulated?

The mechanism of the stress response, known to be highly hormonal in nature, has been well defined (Brown et al., 2005; Domes, Heinrichs, Reichwald, & Hautzinger, 2002; Elzinga & Roelofs, 2005; Selye, 1993). Research on the interaction between stress and cognition, however, is largely limited to the area of executive-attentional processes, i.e. WM and focused attention (al'Absi, Hugdahl, & Lovallo, 2002; Hoffman & Al'Absi,

2004). Less is known about the relationship between stress and decision-making, although evidence that stress can impact general decision-making abilities exists (Arnsten, 1998). In one study it was observed that social stress, induced via anticipation of an upcoming public speech, altered performance and risk tendencies on the Iowa Gambling Task (Preston, Buchanan, Stansfield, & Bechara, 2007). It is unclear how experienced rather than anticipated stress might influence our basic risk preferences, as well as overall decision making mechanisms within specific domains (e.g. loss and gain). That is, are our basic decision-making heuristics influenced by exposure to environmental stressors?

The objective of the Experiment 1 was to examine the interaction between acute physiological stress, in the form of the well-documented cold pressor task, and financial decision-making. Given the association between stress and impulsivity (Joseph, Dalgleish, Thrasher, & Yule, 1997), one hypothesis is that participants would show increased risk-seeking behaviors overall. Given the impact of framing on decision-making, however, it is also possible that the influence of stress may vary by domain (whether a choice is phrased as a possible gain or loss). To explore this, sets of gambles that were presented in either the loss or gain domain were generated. That is, participants chose between two potentially negative outcomes (loss domain) or between two potentially positive outcomes (gain domain) of equal expected value but varied probability. Thus, by holding valence constant within each trial the influence of stress over participants' decision-making tendencies could be measured in the negative and positive domains separately. In accordance with the model described in Chapter 1, it is hypothesized that participants under stress will exhibit an increased dependence on risk-

taking biases based on the domain of the decision, along the lines of the reflection effects. Participants should, therefore, show increased risk-seeking behavior on loss domain trials but increased risk-aversion on gain domain trials.

2.1.2 Method

Participants

Thirty-three participants were involved in the current experiment. Final data analysis for the financial decision-making task was conducted on 27 of the 33 as three participants withdrew prior to completion, and three failed to meet the task requirements by missing an excessive number of trials (13 females, 14 males, mean age = 21.08 years, SD years = 5.51). Participants were undergraduate students at Rutgers University – Newark, and participated for coursework research credits. Participants were also told that they would receive compensation based on their performance, namely the summed outcomes of one random gamble from each of the four task blocks. Additional compensation ranged from $0 - $4.00.

Procedure

Participants completed four blocks of cognitive tasks, each block involving first (1) a WM control task and second (2) a financial decision-making task. Prior to each block of the financial decision-making task, concurrent with the WM task, participants were exposed to either a no stress control procedure or an acute physiological stress procedure. All participants completed two blocks of the task under no stress and two under stress for a total of four blocks in all.

Stress Induction

Acute physiological stress was induced by immersion of the participants' dominant hands in ice cold water (4º C) for two minutes. This procedure, known as the cold pressor task, has an extensively documented history as an acute stressor (e.g., Ferracuti et al., 1994; Loyke, 1995; Patil et al., 1995). Administration of this procedure before the second two blocks of behavioral tasks comprised the "stress" condition. A no stress control condition required immersion of the participants' dominant hand in room temperature water (25º C) for two minutes. This procedure was administered twice concurrent with the working memory control task described below, but prior to each of the first two blocks of the financial decision-making task. Due to the lingering effects of the stress response, once initiated, the order of the stress conditions was not counterbalanced.

Working Memory Control Task

During each immersion, prior to the financial decision-making task, participants performed a delayed-response word recognition task. This task served as an additional manipulation check for the stress induction procedure, as the cold pressor has been found to influence executive processes such as WM (e.g., Patil et al., 1995). Participants were presented with a list of sixteen words with an emotionally neutral valence for 30s followed by a 17s fixation. They then performed a recognition task during which they viewed a list of 6 studied and 6 non-studied words, each for 2s followed by a 4s fixation. The task required that participants verbally indicate whether or not each word had been present in the list they had previously studied. Based on the results of previous work

examining the effects of cold stress on WM (Patil et al., 1995), it is hypothesized that participants' performance will be impaired under stress.

Financial Decision-making Task

After the WM control task, immediately after acute stress exposure had terminated, participants were presented with a gambling task that involved a choice between two alternatives of equal expected value, but varied probability. On a given trial, both choices were presented in either the loss or gain domain: a possibility to "lose" or to "win" money respectively. This allowed for the collection of data on risk-taking decisions in both domains.

There were two sets of gambles used in both the loss and gain domains, all with equivalent expected value. In one set, participants were faced with a decision between an 80% chance of losing $0.75 or a 20% chance of losing $3.00 (Loss domain, see Figure 2.1). On another trial, however, participants might be presented with an 80% chance of winning $0.75 or a 20% chance of winning $3.00 (Gain domain, see Figure 2.1). A second set of gambles comprised a choice between a 60% chance of losing (gaining) $1.00 and a 40% chance of losing (gaining) $1.50. Two different sets of gambles were generated in order to provide variety, engaging participants in the task. In order to gain increased power for data analysis purposes, data from both sets were collapsed within a domain. Stimuli were counterbalanced for order of presentation, and side of the screen each choice was presented on.

There were a total of 160 gambles presented over the entire experiment; 80 per stress condition. Within a stress condition, 40 were presented in the loss and 40 in the gain domain. Finally, within a domain 20 gambles were from the first set (80/20%) and

20 were from the second set (60/40%). Participants had 4s to process the stimulus and make a decision, followed by a 5s fixation. They were then presented with feedback based on their choice for 1s, followed by another 5s fixation. Feedback, which accurately reflected the probability associated with each choice throughout the experiment, was presented as a confirmation of the dollar amount of their loss or gain or a statement that they did not lose or gain money based on their decision for that trial.

Behavioral and Post-experimental Measures

Choosing the option associated with a lower probability of occurring was considered a "risky" choice, while choosing the higher probability option was deemed a "conservative" choice. This framework allowed us to probe the interaction between the variables of interest in the experiment: (a) individuals' physiological state (No-stress x Stress), (b) the decision domain (Loss x Gain), and (c) participants' chosen decision-making strategy (Risky x Conservative) on a given trial. Reaction time was recorded for choices made in the financial decision-making task.

Skin conductance levels (SCL) were recorded throughout the entire experiment. Acquisition of SCL data permitted examination of the difference in physiological states associated with participants' behavior in the no stress and stress conditions. A further exploratory analysis of SCL during specific decisions was also conducted. SCL was assessed using shielded Ag-AgCl electrodes attached to the middle phalanges of the second and third fingers of participants' non-dominant hand using a BIOPAC systems skin conductance module. Offline data analysis of SCL waveforms was conducted using AcqKnowledge software. The extent of SCL was assessed as the average level of skin conductance in microsiemens (μs), within the 0.5 to 4.5 s window following onset of

stimulus presentation (Fredrikson, Annas, Georgiades, Hursti, & Tersman, 1993). Data were then normalized using a square root transform (Levey, 1980). SCL was acquired during the financial decision-making task. Measures of SCL activity over the entire task as a whole, as well as the peak-to-peak SCL at each individual trial, were computed.

Participants completed three questionnaires at the end of the experiment. One was a post-experimental questionnaire asking participants to rate their experience of the experiment (including their subjective experience of the cold pressor task) on a 7 point Likert Scale. The second was intended to measure risk-preference in financial decision-making situations, based on the work of Holt and Laury (2002). The third was the BIS/BAS, a survey which measures participants' sensitivity to aversive (BIS) versus rewarding (BAS) information and stimuli (Carver & White, 1994).

2.1.3 Results

Effect of the Acute Stress Induction

In order to assess the efficacy of the stress induction procedure, the average SCL waveform within each condition was used to compare blocks 1 and 2 (no stress control) with blocks 3 and 4 (acute stress) of the task. A paired t-test was performed on participants' average level of SCL in microsiemens (μs) for all data points in each combined stress condition. This test revealed that SCL was significantly elevated in the acute stress condition (M = 2.86, SD = 1.01) as compared to the no stress control (M = 2.58, SD = 0.98), $t(26) = -5.50$, $p < .001$, $d = -0.28$ (see Figure 2.2), suggesting that decisions following the stress induction procedure were in fact made under the influence of stress. Participants' answers to the post-experimental questionnaire indicated that the

cold pressor task resulted in subjective stress levels that were elevated significantly above chance, $t(26) = 4.12$, $p < .001$, $d = 1.13$. Performance in the risk-preference questionnaire was not analyzed due to the failure of multiple subjects to properly understand and implement the instructions.

Effects of Acute Stress on the Working Memory Control Task

As expected, a two-tailed paired t-test indicated that participants' accuracy on the WM control task was significantly worse under acute stress ($M = 0.81$, $SD = 0.12$) as compared to no stress ($M = 0.86$, $SD = 0.07$), $t(26) = 2.96$, $p < .01$, $d = 0.74$. This provides further support for the efficacy of the cold pressor task as a stress induction procedure, while suggesting that stress can have detrimental effects on cognitive performance.

Effects of Acute Stress on Financial Decision-making

To examine the effect of acute stress on financial decision-making, a 2 (stress condition: no stress vs. acute stress) x 2 (decision domain condition: loss vs. gain) repeated-measures analysis of variance (ANOVA) was conducted on strategy choice data (risky vs. conservative). These data were computed as the proportion of times a participant made risky or conservative choices in each stress x decision domain condition, compared to the total number of available choices (with null trials removed). The total proportion of risky vs. conservative choices within a condition summed to 1, therefore analyses were conducted on risky choice data only to avoid redundancy. A significant main effect of decision domain was observed, $F(1, 26) = 20.41$, $p < .001$, $\eta_p^2 = 0.440$. Post-hoc one-tailed t-tests indicated that in the no stress condition participants made significantly more risky choices in the loss ($M = 0.62$, $SD = 0.20$) as compared to

gain domain (M = 0.41, SD = 0.20), $t(26) = 2.85$, $p < .01$, $d = 1.22$). Thus, reflection was observed in participants' decision-making.

In addition, a 2-way interaction between stress and decision domain on risk-taking behavior was observed, $F(1, 26) = 6.40$, $p < .05$, $\eta_p^2 = 0.197$. Post-hoc one-tailed paired t-tests indicate that significantly fewer risky decisions (i.e., increased conservatism) were made on gain-domain trials under acute stress (M = 0.32, SD = 0.20) compared to no stress (M = 0.41, SD = 0.24), $t(26) = -2.574$, $p < .01$, $d = -0.45$ (See Figure 2.3). On loss-domain trials, participants a marginal effect was observed such that participants made a higher number of risky decisions under acute stress (M = 0.67, SD = 0.20) over no stress (M = 0.62, SD = 0.20), $t(26) = 1.55$, $p = .07$, $d = 0.26$. Given the enhanced reaction to losses exhibited by most individuals (i.e., loss aversion; Kahneman & Tversky, 1979) is plausible that reflection manifested as a marginal effect in the loss domain due to a higher baseline level of risky choices. These results support the hypothesis that acute stress exaggerates the reflection effect.

Collapsing across decision-making strategy, a 2 (no stress vs. acute stress) x 2 (loss vs. gain) repeated-measures ANOVA was performed on reaction time data. A significant ordinal interaction was observed, $F(1, 26) = 10.65$, $p < .01$, $\eta_p^2 = 0.290$**.** Under no stress, participants performed significantly faster on gain (M = 2052.98, SD = 291.88) as compared to loss trials (M = 2325.11, SD = 293.34), $t(26) = 6.55$, $p < .001$, d = 0.93. Notably, acute stress led to faster overall performance with roughly equivalent speed on gain/loss trials.

Post-experimental Measures

See Table 2.2 for a correlation matrix containing the central variables of interest in Experiment 1. Analysis of the BIS/BAS survey data indicated a covariate of interest in the form of participant's behavioral inhibition scores (BIS). When entered as a covariate into the aforementioned 2 (stress condition: no stress vs. acute stress) x 2 (decision domain condition: loss vs. gain) repeated-measures ANOVA performed on participant's strategy choice data, a significant domain by BIS interaction was observed, $F(1, 25) = 10.46$, $p < .01$, $\eta_p^2 = 0.295$. In order to further explore the nature of this relationship two separate moderated multiple regressions were performed (see Table 2.1). In Step 2 proportions of gain (and loss) domain risky strategy choices were regressed onto the predictors of Stress Condition and BIS, with the interaction being tested in Step 2. No significant interaction was observed in either domain (see Table 2.1), although the effect of BIS was significant in both domains. Analysis of simple slopes (Aiken & West, 1991) indicated a significant negative relationship between BIS score and risky strategy choices in the gain domain was $b = -0.03$, $t = -3.77$, $p < .001$ (see Figure 2.4). The relationship between BIS and risky strategy choices, however, was positive in the gain domain, $b = 0.02$, $t = 2.85$, $p < .01$. Thus, as participants' BIS increased they made significantly fewer risky choices in the loss domain – but significantly more in the gain domain.

Gender Analyses

Data were analyzed with respect to gender in order to examine possible differences in strategy choice and stress reactivity along those lines. There was no significant interaction between gender, stress, and decision domain on risky choices, $F(1,25) = 0.11$, $p > .10$, $\eta_p^2 = 0.004$, or conservative ones, $F(1,25) = 0.06$, $p > .10$, $\eta_p^2 =$

0.002. In addition, there was no effect of gender on SCL (as measured in the aforementioned analysis) when participants were exposed to acute stress, $t(26) = 0.003$, $p > .05$, $d = 0.10$, or the no stress control procedure, $t(26) = 0.25$, $p > .05$, $d = 0.001$.

2.2: Experiment 2: Ruling out a practice effect by inducing stress first

2.2.1 Introduction

One notable limitation of Experiment 1 was the absence of counterbalanced stress conditions (i.e. no stress always came before acute stress). This decision was made in order to prevent the lingering effects of stress from influencing subsequent performance, but it leaves the results of Experiment 1 open to the confounding effects of practice. For example, it is possible that increasing familiarity with the financial decision-making task might in-and-of itself alter risk-taking tendencies. Experiment 2 was designed to address this concern, by examining the behavior of individuals on the same financial decision-making task who are exposed to acute stress from the onset of the experiment. If the previously observed results were due to a practice effect, then the results of Experiment 2 under stress should be decreased compared to Experiment 2 stress session. It is hypothesized that participants will show a similar pattern of behavior under acute stress in Experiment 2, suggesting that practice effect is not a factor.

2.2.2 Method

Participants

Thirty-three participants were involved in the current experiment, however final data analyses were only completed on 27 as 6 participants failed to meet the task

requirements by missing an excessive number of trials (14 females, 13 males, mean age = 20 years, SD years = 2.34). As the participants performed as required on the working memory control task, their data were analyzed for that task and post-experimental questionnaires pertaining to the acute stress induction only. Participants were undergraduate students at Rutgers University – Newark, and participated for coursework research credits. Participants were also told that they would receive compensation based on their performance, namely the summed outcomes of one random gamble from each block. Additional compensation ranged from $0 - $4.00.

Procedure

The procedure used in Experiment 2 was virtually identical to that used in Experiment 1. Order of presentation of all trials was identical to that used in Experiment 1. However, in Experiment 2 participants completed the four blocks of cognitive tasks encompassing (a) a WM control task and (b) a financial decision-making task on two consecutive days. On the first day, prior to each of the two blocks of tasks participants were exposed to the acute stress procedure used in Experiment 1. On the second day, participants completed two blocks of the task after the no stress control procedure only. Thus, the design of Experiment 2 involved a reversal of the order of acute stress administration as compared to Experiment 1 – with the second half taking place on a different day in an attempt to avoid data acquired during the no stress control blocks from being contaminated by the effects of stress administered first. Conditions were counterbalanced with respect to order – all trials present in Experiment 1 were represented in Experiment 2.

Stress Induction

Acute physiological stress was induced in exactly the same way as Experiment 1, via a 2-minute immersion in ice-cold water concurrent with a working memory control task. The no stress control condition required immersion of the participants' dominant hand in room temperature water (25º C) for two minutes, as in Experiment 1.

Working Memory Control Task

The working memory control task was identical to that used in Experiment 1.

Financial Decision-making Task

The financial decision-making task used in Experiment 2 was identical to that used in Experiment 1.

Behavioral and Post-experimental Measures

The behavioral and post-experimental measures acquired in Experiment 2 were identical to those acquired in Experiment 1.

2.2.3 Results

Effect of the Acute Stress Induction

In order to assess the efficacy of the stress induction procedure when administered first, SCL was measured during each block of the financial decision-making task. As in Experiment 1, SCL was significantly elevated when participants were exposed to acute stress (M = 3.06, SD = 0.98) as compared to the no stress control procedure (M = 2.73, SD = 1.08), $t(26) = 2.064$, $p < .05$, $d = 0.32$. Furthermore, the SCL waveform was then averaged to compare blocks 1 and 2 (acute stress; M = 2.73, SD = 1.08) of Experiment 2 with blocks 3 and 4 (acute stress; M = 2.86, SD = 1.01) of Experiment 1. A between-

subjects t-test indicated no significant difference between the two groups existed, $t(26) = 0.433$, $p > .05$, $d = 0.12$, although SCL was greater under acute stress in Experiment 1. This suggests that decisions following the stress induction in Experiment 2 were made under levels of stress comparable to Experiment 1. Participants' answers to the post-experimental questionnaire indicated that the cold pressor task resulted in subjective stress levels that were elevated significantly above chance, $t(32) = 4.86$, $p < .001$, $d = 1.19$.

Effects of Acute Stress on the Working Memory Control Task

In contrast to Experiment 1, participants exhibited no significant difference in their performance on the working memory control task under acute stress ($M = 0.86$, $SD = 0.10$) as compared to no stress ($M = 0.83$, $SD = 0.09$), $t(26) = -1.50$, $p > .10$, $d = -0.30$. Participants more accurately performed the working memory task under acute stress in Experiment 2 ($M = 0.86$, $SD = 0.10$) as compared to Experiment 1 ($M = 0.81$, $SD = 0.12$), but this difference was not significant as measured by between-subjects t-test, $t(52) = -1.92$, $p > .05$, $d = 0.52$.

Effects of Acute Stress on Financial Decision-making

To examine the effect of acute stress on financial decision-making, a 2 (stress condition: no stress vs. acute stress) x 2 (decision domain condition: loss vs. gain) ANOVA was conducted on strategy choice data (risky vs. conservative). These data were computed in the same manner as was presented in Experiment 1. The total proportion of risky vs. conservative choices within a condition summed to 1, therefore analyses were conducted on risky choice data only to avoid redundancy. A significant main effect of decision domain was observed, $F(1, 26) = 30.52$, $p < .001$, $\eta_p^2 = 0.540$.

Examining the results of Experiment 2 via paired t-test, a significant degree of reflection did occur in these data. Participants made significantly more risky choices on loss domain trials (M = 0.64, SD = 0.14), $t(26) = 5.82$, $p < .01$, $d = 2.2$, and significantly fewer risky choices (i.e., increased conservatism) when a decision was in the gain domain (M = 0.39, SD = 0.18), $t(26) = -2.97$, $p < .01$, $d = -1.14$. There was, however, no significant 2-way interaction between stress and decision domain on risk-taking behavior, $F(1, 26) = 0.02$, $p > .10$, $\eta_p^2 = 0.001$.

Given this marked difference between the results of Experiments 1 and 2, additional between-subjects analyses were conducted in order to examine possible explanations. Using post-hoc independent t-tests, participants' strategy choices in each domain while under stress in Experiment 1 were compared with those of the Experiment 2 participants (who were also exposed to stress). Note that data for participants in Experiment 1 were acquired after performance on two previous no stress control blocks of cognitive tasks, whereas the acute stress condition data for Experiment 2 individuals were not. Results indicate that choice of risky strategy choices did not significantly differ from Experiment 1 acute stress levels. This holds true for risky choices on gain domain trials in Experiments 1(M = 0.32, SD = 0.20) and 2 (M = 0.40, SD = 0.18), $t(52) = -1.57$, $p > .05$, $d = -0.43$, as well as risky choices in the loss domain for Experiments 1 (M = 0.67, SD = 0.20) and 2 (M = 0.67, SD = 0.15), $t(52) = 0.50$, $p > .05$, $d = 0.01$.

To further examine possible differences in the effect of acute stress on risk-taking when stress is administered first, without relying on a null result, a second more focused analysis was also conducted. This analysis utilized skin conductance levels to reduce inter-subject variability in stress reactivity, minimizing the impact of this factor on a

between-subjects comparison between the no stress condition of Experiment 1 and the stress condition of Experiment 2. These two data sets are composed of exactly the same experimental trials, presented in exactly the same order, varied only with respect to the application of stress. First, participants from Experiments 1 and 2 were yoked by their average level of skin conductance while making decisions under acute stress. Thus, only participants who exhibited similar levels of skin conductance under acute stress were included in the analysis. Having met that initial criteria, only those Experiment 1 participants who showed a marked *decrease* in skin conductance while making decisions under no stress (as compared to acute stress) were allowed to remain in the analysis. If an Experiment 1 participant showed no change or an increase in skin conductance moving from the acute stress to the no stress condition that participant (and their yoked Experiment 2 partner) were excluded. Finally, using this subset a between-subjects comparison were made between the strategy choices for Experiment 1 participants under no stress (n = 16) and Experiment 2 participants under stress (n = 16).

Notably, this analysis uncovered a significant increase in risky strategy choices on loss domain trials from the no stress condition of Experiment 1 (M = 0.41, SD = 0.23) to the stress condition of Experiment 2 (M = 0.76, SD = 0.12), $t(25.34) = -2.49$, $p < .05$, $d = 0.88$ (see Figure 2.5). No significant decrease of risky strategy choices was observed in the gain domain, $t(30) = -1.08$, $p > .10$, $d = -0.38$. By demonstrating a between-subjects increase in risk-taking associated with stress-related increases in skin conductance, this analysis bolsters analyses already presented in support of the interpretation that the results of Experiment 1 are not due to a practice effect.

Post-experimental Measures

See Table 2.3 for a correlation matrix containing the central variables of interest in Experiment 2. Performance on the risk-preference questionnaire was not analyzed due to the failure of multiple subjects to implement instructions. The results of the BIS/BAS survey did not significantly covary with participants' choice behavior in this experiment, nor did self-report ratings of subjective levels of stress resulting from the acute stress procedure.

2.3: Experiment 3: Ruling Out a Practice Effect by Removing Stress

2.3.1 Introduction

Although Experiment 2 indicated that a practice effect was not responsible for the results of Experiment 1, additional concerns lead to a final experiment to resolve the issue completely. Because high variability in choice behavior between individuals weakens conclusions drawn from a between-subjects comparison, a within-subjects experiment with no acute stress exposure was designed. In Experiment 3 it is hypothesized that – when exposed to a no stress control procedure alone in the place of acute stress – participants' strategy choices will remain consistent over the four blocks of trials, showing no evidence of a practice effect. Evidence that no practice effect exists at the within-subjects level will help to bolster the results of between-subjects comparisons indicating that no practice effect was present in Experiment 1.

2.3.2 Method

Participants

Twenty-one participants were involved in the current experiment (11 females, 10 males, mean age = 20.09 years, SD years = 3.24). Participants were undergraduate students at Rutgers University – Newark, and participated for coursework research credits. Participants were also told that they would receive compensation based on their performance, namely the summed outcomes of one random gamble from each block. Additional compensation ranged from $0 - $4.00.

Procedure

As was previously discussed, the order of presentation of the stress conditions in Experiment 1 made it impossible to test for the presence of practice effects. Experiment 3 was designed to address that concern. The procedure used in Experiment 3 was virtually identical to that used in Experiment 1. Order of presentation of all experimental trials was identical to that used in Experiment 1, in all conditions. Participants completed all four blocks of cognitive tasks. Prior to each block of the financial decision-making task, participants were exposed to *only* the no stress control procedure described for Experiment 1. Every effort was made to ensure that Experiment 3 would take place in exactly the same way as Experiment 1 – with the sole exception of no acute stressor being used.

No-stress Control Procedure

The no stress control procedure required immersion of the participants' dominant hand in room temperature water (25º C) for two minutes. This procedure was administered four times concurrent with the working memory control task, but prior to

each of the four blocks of the financial decision-making task. No cold stress was applied in Experiment 3.

Working Memory Control Task

The working memory control task was identical to that used in Experiment 1.

Financial Decision-making Task

The financial decision-making task used in Experiment 2 was identical to Experiment 1.

Behavioral and Post-experimental Measures

The behavioral and post-experimental measures acquired in Experiment 3 were identical to those acquired in Experiment 1, save that SCL was not acquired. Participants were connected to SCL equipment in exactly the same way as those in the prior two experiment (where SCL actually was recorded) in order to control for any effect of that experience on their behavior.

2.3.3 Results

Effects of the No-stress Procedure on the Working Memory Control Task

A paired t-test comparing the first two blocks of the WM task with the second two blocks yielded evidence of a learning effect on this task, in that participants performed better on the second two blocks (M = 0.92, SD = 0.06) than the first two (M = 0.88, SD = 0.06), $t(20) = -2.23$, $p < .05$, $d = -0.61$. Additionally, WM task scores from Experiment 3 were compared with those scores from Experiments 1 and 2 that were acquired under acute stress *and* at the temporal location in the experiment (i.e. acute stress blocks 3 and 4 from Experiment 1 with no stress blocks 3 and 4 from Experiment 3) by between-subjects

t-test (see Figure 2.6). Results indicate that participants performed significantly worse under acute stress in Experiment 1 (M = 0.80, SD = 0.11), $t(42.80) = -5.09$, $p < .05$, $d = -1.43$, as compared to Experiment 3 (M = 0.92, SD = 0.06). This effect also manifested in the Experiment 2 (M = 0.86, SD = 0.10) comparison, $t(46) = -2.58$, $p < .05$, $d = -0.77$. Please note that values were adjusted in the Experiment 1 to 3 comparison due to an inequality of variance between the two groups.

Testing for Practice Effects in Experiment 3

Two 2 (combined block numbers 1 & 2 vs. 3 & 4) x 2 (decision domain condition: loss vs. gain) repeated-measures analyses of variance (ANOVA) were performed on participants' strategy choice data. As was hypothesized, there was no effect of order on risky strategy choices, $F(1, 20) = 0.95$, $p > .05$, $\eta_p^2 = 0.05$). A significant main effect of decision domain on strategy was also observed, along the lines of the reflection effect. More specifically, participants made significantly more risky choices on loss trials (M = 0.63, SD = 0.24) and fewer on gain trials (M = 0.42, SD = 0.29) across blocks, $F(1, 20) = 6.06$, $p < .05$, $\eta_p^2 = 0.233$.

Post-experimental Measures

See Table 2.4 for a correlation matrix containing the central variables of interest in Experiment 3. Post-experimental questionnaires indicated that the no stress control procedure resulted in subjective stress levels that were significantly below chance levels, $t(21) = -8.35$, $p < .001$, $d = -2.59$. The results of the BIS/BAS survey did not significantly covary with participants' choice behavior in this experiment, nor did self-report ratings of subjective levels of stress resulting from the acute stress procedure.

General Discussion

Experiment 1 suggests that acute stress exposure alters decision-making by modulating decision-makers' risk-taking. Specifically, it was observed that participants' risk-taking varied along the lines of PT's reflection effect hypothesis -- people were risk-seeking for decisions in the loss domain but risk-averse for gain domain decisions. Most interesting is the manner in which acute stress modulated these established levels of risk-taking. Participants in Experiment 1 exhibited a significantly higher degree of reflection after being exposed to stress. It may be that, under stress, people come to rely more heavily on these risk-taking heuristics – exacerbating an already prevalent decision-making bias. By falling back on existing risk-taking heuristics, a decision-maker might be able to better maintain organized and goal-directed behavior under the disruptive influence of stress.

Day-to-day decision-making unavoidably occurs in situations subject to various stressful environmental demands. Despite this, individuals must continue to make informed and goal-oriented decisions. Attempting to understand how to overcome or cope with the influence of stress while making such decisions is vitally important, but the first step is to probe the interaction between the state created by a stressful environment and how decisions are performed in that environment. These experiments suggest that stress modulates decision-making within a specific domain valence, resulting in further reliance on the use of decision-making heuristics.

One potential explanation for this effect is that stressors may result in premature closure – that is, termination of the decision-making process before all possible alternatives, and their respective outcomes, have been rationally appraised (Janis, 1993;

Keinan, Friedland, & Ben-Porath, 1987). In this way the stress response may limit the range of perceived viable options that offer a solution to a given problem, short-circuiting decision-making abilities. Given the significant decrease in reaction times under stress, this explanation is a plausible one that can drive future research. An alternative, yet compatible, explanation is that stress interferes with the integrity of the brain's executive systems, leading to an exaggerated reliance on heuristics as a means for maintaining organized and goal-directed behavior. Stressed participants' poor performance on a WM control task in the current experiment supports this hypothesis, along with previous work on the interaction between stress and executive-attentional processes (al'Absi et al., 2002; Hoffman & Al'Absi, 2004).

An alternative hypothesis for this experiment might have been that under stress participants would exhibit increases in risk-taking behavior overall. That hypothesis, however, fails to capture the true nature of how acute stress differentially modulates risk-taking in the loss and gain domains. If acute stress disrupts a person's ability to make organized and goal-directed decisions, resulting in an exaggerated reliance on existing risk-taking heuristics, it would be a mistake to assume that the disruption must result in more risk-seeking behavior overall. A preference for making overly conservative choices may result in the same degree of decision-making bias as a preference for making risky choices, perhaps causing roughly equivalent amounts of monetary loss in real world terms. Thus, our results indicate that acute stress leads to increases in *impulsivity* – an effect which manifests differently behaviorally in the loss vs. gain domain.

One limitation of Experiment 1 involved the fact that the order of presentation for the stress vs. no stress control conditions was not counterbalanced. This decision was

made with careful consideration given to the consequences of that choice. Evidence from past research indicates that cold induced acute stress is sustained over time. McRae *et al.* (2006), for instance, observed immediate and sustained cortisol increases after exposure to cold stress. These results are consistent with other findings investigating cortisol kinetics in response to the cold pressor task (i.e., Washington, Gibson, & Helme, 2000). Therefore it was decided not to counterbalance, in order to prevent stress (if administered first) from influencing subsequent no stress blocks of trials. Experiments 2 and 3 were designed to address the possibility of a practice effect confounding the results observed in Experiment 1.

In Experiment 2 the same financial decision-making task used in Experiment 1 was administered – this time with participants exposed to acute stress at the onset of the task rather than at the end. Notably, no significant interaction was observed between stress condition and decision domain in Experiment 2 – perhaps due to the lingering effects of stress administered first. Post-hoc analyses did indicate, however, that Experiment 2 strategy choices under stress did not significantly differ from those made under stress in Experiment 1 – implying that participants made similar levels of (exaggerated) reflective choices under acute stress. Furthermore a specialized analysis during which Experiment 1 and 2 participants were yoked according to SCL under acute stress, followed by between-subjects comparison of choice behavior from Experiment 1 participants under no stress to Experiment 2 participants under acute stress, did indicate that acutely stressed Experiment 2 participants exhibited higher levels of reflection in the loss domain. Future research on the time course and contextualization of participants'

responses to acute stress, which appeared to contaminate the data acquired in the no stress blocks of Experiment 2, will be of great use for planning future designs.

Experiment 2 did, however, raise additional concerns – namely that a between-subjects comparison of the type just discussed might be subject to the high level of inter-subject variability observed in choice behavior on financial decision-making tasks, obscuring the validity of the results. Despite that complication, an analysis relying on measures of skin conductance to yoke subjects with similar levels of stress reactivity demonstrated that participants did exhibit higher levels of risk-taking under stress when decisions were presented in the loss domain. In Experiment 3 participants performed the same task as in Experiment 1 after exposure to *only* a no stress control procedure. Within-subject comparisons of choice behavior indicate that strategy did not differ as a function of which block of trials the participant was performing. Despite the choice not to counterbalance in Experiment 1, Experiments 2 and 3 lend support to the results of Experiment 1 by indicating that no practice effect was present.

The current findings have implications for understanding how a person's environment might interfere with his ability to make decisions. If the domain-dependent risk-taking biases put forward by Prospect Theory become exaggerated under stress, uninformed decision-makers might become dangerously unreliable simply due to normal job stress related to their profession. Acute stress has previously been studied in multiple demanding workplace environments, such as in the context of emergency medical services. Physiological measures of stress are elevated during performance in these types of environments (e.g., Kozena & Frantik, 2001). It may also be the case that some individuals are predisposed towards sensitivity to this effect. One example would be

drug-abusers who have compromised specific neural systems related to inhibitory control and reward-related learning via their drug use (Jentsch & Taylor, 1999), and are therefore more likely to relapse when stress further interferes with the functioning of said systems. Given that the consequences of a person making a poor decision in such situations are dire, gaining an understanding of how stress impacts such processes is imperative.

In addition, our findings are relevant for researchers investigating decision-making in a number of contexts. Experimental designs involving time pressure, the performance of exacting mental computations, and even the use of intimidating neuroimaging technologies might be influenced by stress. For example, magnetic resonance imaging technology can be loud, restricting (e.g., the narrow confined space of an MRI bore), and even frightening for some individuals (Raz et al., 2005). It is plausible that environmental demands of this type are stressful for some research participants, in addition to any anticipatory stress an individual might feel prior to an experiment. Thus, decision-making researchers may be unknowingly shifting the risk biases of their participants before an experiment has even begun. Additional research is necessary to clarify these concerns.

Much evidence points to gender differences in stress reactivity (e.g., Kajantie & Phillips, 2006; Wang et al., 2007). For instance, in one study Preston et al. (2007) observed that under anticipatory stress males exhibited poorer explicit knowledge of, and less advantageous performance on, the Iowa Gambling Task – whereas females' explicit knowledge and performance improved. In the current experiment, there were no gender differences in participants' choice of strategy or stress reactivity as measured by SCL. One explanation for this could be that the decision-making processes examined in this

study are not, in fact, dissociable by gender. Another would be that SCL, which indexes the arousal of an individual, may not be as sensitive to subtle differences in stress reactivity as some other dependent measures (i.e. cortisol levels). Finally, past research indicates that gender differences in stress reactivity are especially prominent at the neural level (Jackson, Payne, Nadel, & Jacobs, 2006). Incorporation of these measures into future designs may be helpful in clarifying the role of gender in stress and decision-making interactions.

While responses to acute stress may have evolutionarily adaptive value, higher-order cognition sometimes becomes compromised in the service of enacting instinctual responses designed to deal with such stress. In light of this, examining the interaction between stress and decision-making processes is an important endeavor. Future research on this topic should involve techniques sensitive to the activity of the brain, in order to elucidate exactly how stress interacts with decision-making at a neural level. It is possible that cognitive techniques, such as emotion regulation strategies (Gross, 2002), might be devised to aid an aware decision-maker in overcoming increased levels of bias resulting from stress. Such techniques, once developed, would be extremely useful to those people subjected to extreme levels of stress. Furthermore, addition research is necessary to examine whether or not this stress effect generalizes to other types of decision-making. It is possible, for example, that a different pattern would emerge were the task itself different.

Chapter 3

Experiment 4: Interactions of acute stress and simple preferences following instrumental conditioning.

3.1 Introduction

In the last chapter, it was established that acute stress modulates risk-taking in a financial decision-making task. Under acute stress, in the form of the cold pressor task, participants exhibited significantly higher levels of reflection than when exposed to a no-stress control procedure. This finding portrays one way in which acute stress might bias rational decision-making, by leading individuals to make even more conservative choices on gain domain decisions (and more risky choices in the loss domain) than would normally be expected due to the typical presence of reflection in choice behavior. But why would acute stress modulate behavior in this way?

Although it was suggested earlier that this modulation is accomplished through an increased reliance on more automatized behaviors under stress, the validity of that proposal remains an open question. Another question of interest is whether or not this effect is generalizable to other types of decision-making. Therefore, in an attempt to address both questions Experiment 4 will examine the impact of acute stress on decisions influenced by preferences acquired via instrumental conditioning. If acute stress of a sufficient intensity increases reliance on more automatized forms of behaviors, due to a reduction in the ability to make decisions based on higher-order deliberation and reasoned thought, then acute stress should also modulate risk-taking in a paradigm involving this different type of decision-making.

In order to consider the effects of acute stress on instrumentally conditioned decisions, it is important to briefly explore the difference between controlled and automatic processes involved in the regulation of behavior and information (for review, see Bargh & Morsella, 2008; Kihlstrom, 1987). Controlled processing is characterized by awareness, intentionality controllability and expenditure of cognitive effort (Bargh, 1996; Shiffrin & Schneider, 1977a, 1977b). Automatic processes are often associated with the opposites of those characterizations – unawareness, unintentionality, a lack of control and little to no expenditure of cognitive effort (Bargh, 1996). It is vital to note, however, a gray area exists between these four factors which blurs the boundaries between controlled and automatic processes.

One proposal states that, rather than a dichotomy, these types of processes are best characterized as a continuum of automaticity that ranges from completely controlled to completely automatic (Bargh & Chartrand, 1999). Under this framework regulation information processing and behavior can range from preconsciously automatic at the automatized end of the spectrum, to goal-directed automaticity in the middle, to completely conscious and effortful processes at the controlled end. The line of research presented in this dissertation focuses on the midpoint of this spectrum of automatic/controlled – cognitions and behaviors that are largely automatized, but goal-directed. For example, research indicates that an individual primed by a specific concept may exhibit a large degree of intentional bias in subsequent information processing. In one experiment, participants primed with words related to memorization versus evaluation of information performed quite differently on a subsequent recall task (Chartrand & Bargh, 1996). Thus, automatic and unconscious – but intentional –

processing of information has been observed to guide an individual towards specific cognitions. If an individual can be influenced by automatic, but intentional, processes outside of awareness it is plausible that behavior might be similarly guided to promote intentions.

A prominent example, known as the endowment effect, originates from the field of economics (Thaler, 1980). In one experiment, researchers at Duke University examined the willingness of individuals to pay for, and sell, tickets to a highly anticipated sporting event (Carmon & Ariely, 2000). Whereas people who did not have tickets were willing to pay $170 on average to acquire one, those who did acquire a ticket were willing to sell theirs for an average of $2,400 – a massive discrepancy. This is a violation of standard economic predictions, which state that the price a rational decision-maker is willing to pay for an item should equal the price they are willing to accept for it. What is most relevant about this example is that people are usually unaware that such a discrepancy exists. Thus, just as information processing may be both automatized and goal-directed so too can observable behaviors.

One explanation for this phenomenon is found in the literature on Prospect Theory, in the form of loss aversion (Kahneman & Tversky, 1979). Essentially, this proposal states that the negative hedonic impact of losses is roughly two times stronger than the positive hedonic impact of gains. This would imply that losing an item, even in exchange for monetary compensation, is more painful than deciding not to pursue purchase of that item – resulting in the aforementioned gap in willingness to pay versus accept payment for a single item. It is plausible that the reflection effect, discussed in Chapters 1 and 2, may be a similar automatized reaction to losses and gains.

One likely mechanism by which such reactions to perceived losses and gains may become automatized is through conditioning. If such behaviors are conditioned, it is even possible that acute stress might enhance their expression. Previous research has established that various types of stress exert an influence over conditioned learning (e.g., Shors et al., 1992). For example, early research demonstrated that uncontrollable stress can alter learning on a subsequent task resulting in a phenomenon now known as learned helplessness (Overmier & Seligman, 1967). More recent research indicates that acute stress can alter how a given stimulus comes to be associated with a reward in classical conditioning – conditioned heart rate increases in response to a conditioned stimulus is one example (Wilson *et al.,* 1975). Other work in this context confirms the idea that acute stress exposure can enhance formation of learned associations, even after the associations have already been acquired (Shors, Chua, & Falduto, 2001). It is, however, unclear whether or not such effects generalize to instrumental conditioning in humans using money as a reinforcer.

This experiment attempts to examine whether or not the effects of acute stress generalize to decision-making following learning through instrumental conditioning. Based on previous work by Delgado (2007), a reward-related learning paradigm where participants acquire preferences via trial and error learning was used. Specifically, participants underwent several training sessions where they acquired preferences with respect to visual stimuli (i.e., colored squares) via instrumental conditioning (i.e., certain colors predicted positive or negative monetary outcomes). Preference formation was tested after learning by having participants make decisions between those visual stimuli. After preferences were strengthened and developed, participants underwent a reversal

learning procedure where contingencies were altered (i.e., colors predicted different outcomes than they had before), followed by another decision-making task.

One group was exposed to an acute stressor (i.e., cold pressor) prior to the last choice task, while another was exposed to only a no stress control procedure (i.e., room temperature water). Based on research presented earlier in support of the notion that information may be unconsciously processed in the furtherance of automatized goals, two different patterns of choices are hypothesized in the current experiment. One hypothesis holds that, as participants are extensively trained to prefer specific squares in the first two learning tasks, under acute stress they should fall back on such automatized preferences. Under this hypothesis stressed participants would choose squares associated with the initial values more often. Alternatively, acutely stressed individuals could exhibit enhanced instrumental conditioning of the new stimuli in the reversal task in accordance with. Because both hypothesized outcomes involve a shift from deliberative and logical reasoning to a more automatized form of reasoning, in the former case involving falling back on well-learned preferences and in the latter the enhanced acquisition of new learned behaviors through conditioning, support for either hypothesis by the results of the current experiment would corroborate an interpretation that acute stress increases reliance on automatized behaviors.

3.1 Method

Participants

Twenty-eight participants were involved in this experiment (14 females, 14 males, mean age = 19.84 years, SD years = 2.33). Participants were undergraduate students at

Rutgers University – Newark, and participated for coursework research credits. Participants received compensation based on their performance, namely the summed outcomes from each day of one randomly selected gamble from each block of that task. Additional compensation ranged from $0 - $4.00.

Procedure

This experiment took place during two separate experimental sessions, on two consecutive days. On the first day, participants performed two consecutive tasks (see Figure 3.1). First, in a learning task different monetary values (or contingencies) were associated with nine simple visual stimuli in the form of colored squares via instrumental conditioning. Each stimulus was presented for 2s, with an instruction to press a specified keyboard button, either a one or two, within that time period. After making the requested button press participants were presented with the value of the square, which appeared within the boundaries of the square itself for 1s. Importantly, participants were instructed that their responses in this task did not result in actual gains or losses of money. Rather, their task was to learn as much about the squares as possible.

Two monetary values were used, either $1 or $5, and a given square was associated with either a gain or a loss of that amount of money – resulting in stimuli associated with values of +$1.00, +$5.00, -$1.00, or -$5.00. Aside from one of the nine squares, a neutral one associated with a $0.00 value with 100% certainty, the association of each square with its monetary value was probabilistic in nature. That is, the remaining eight squares were associated with their monetary values along two levels of probability which could be thought of as either ‘easy’ or ‘hard’ to learn. For example, an ‘easy’ square might be one associated with a gain of $5.00 in general – but participants were

presented with a "+$5.00" on only 90% of their responses, with the other 10% resulting instead in a presentation "-$5.00". A 'hard' square might also be associated with a gain of $5.00 in general – but with "+$5.00" being presented only 65% of the time, versus a "-$5.00" 35% of the time. Thus, the associations of the eight non-neutral stimuli conformed to a 2 (monetary value: $1 vs. $5) x 2 (value domain: gain vs. loss) x 2 (probability of outcome: easy or 90/10% vs. hard or 65/35%) design (for a detailed list, see Table 3.1).

The second task on day 1 was a decision-making or choice task where participants were asked to choose between various binary permutations of the same set of stimuli, based on what they had learned about them in the last task. In addition one new control stimulus not previously learned was also present, totaling ten stimuli in this task. Stimuli were counterbalanced with respect to the order and manner of presentation. In this choice task, no feedback or value-related information was given after choices were made – but participants were instructed that the monetary outcomes of randomly selected trials would be chosen at the end of the experiment to add to their winnings. Performance on this decision-making task established a pattern of preferences indicative of the degree to which participants had learned the contingencies associated with each stimulus during the previous learning task. After completing the learning and choice tasks on day 1, participants completed each a second time in the same order. Thus, the first day of the experiment served to establish a learned pattern of behavior relative to the rewards associated with this set visual stimuli. If participants did not demonstrate adequate learning by the end of the second choice task (a 70% criterion) they were asked to complete the learning task one more time before ending the session.

On the second and final day of the experiment, participants performed three consecutive tasks (see Figure 3.1). In order to reestablish the contingencies learned during the previous sessions, the first was a repetition of the same choice task from day 1. The second task on day 2, however, involved a new learning task (reversal learning task). In this task, which was identical in design to the earlier learning tasks, the contingencies associated with the same visual stimuli already presented to the participants were altered – and participants were tasked to learn these new contingencies (with no winnings or losses calculated based on their responses, as in the earlier learning task). It is important to note that the monetary values and specific probabilities of reward were not changed. Rather, the nine squares were rearranged such that they were now associated with a new level of the value and probability design discussed earlier.

Finally, in the third task on day 3 participants performed one final choice task (reversal choice task). This task was identical in design to the other choice tasks, save that here participants were instructed to make their choices based on the new contingencies they had just learned in the reversal learning task. Thus, participants were instrumentally conditioned to respond to specific visual stimuli for monetary rewards during the two learning tasks. Participants' decisions between stimuli were then measured in three choice tasks. On day 2 the contingencies associated with the stimuli were altered in one last learning task – and choices based on those new contingencies measured in a final choice task. Acute stress, or a no stress control, was applied immediately prior to the final reversal choice task – after the reversal learning task.

Stress Induction

Acute physiological stress was induced by immersion of the participants' dominant hand in ice cold water (4º C) for two minutes, as was described in Chapter 2. Similarly, a no-stress control procedure required immersion of the participants' dominant hand in room temperature water (25º C) for two minutes. In one condition of the experiment, acute stress will be applied immediately before the reversal preference task on day 2 – after the reversal learning task in which the participant is presented with altered contingencies. In another condition of the experiment, a no-stress control will be applied at that same point in the experiment. By examining participants' performance in the reversal preference task under acute stress, or a no-stress control, the impact of acute stress on decision-making resulting instrumentally conditioned preferences may be examined.

Behavioral Measures

During all learning tasks of the experiment, reaction times were measured and served as the dependent variable. The number of times participants chose specific squares in the choice tasks was another dependent variable, as they indicated of how well participants had assimilated the instrumentally conditioned contingencies presented in the learning tasks. In addition, an advantage of the probabilistic design described earlier is that it allowed for calculation of the expected utility (see Chapter 1.6) of each square. More specifically, the value of each stimulus was separately multiplied by the probability it would result in a gain and loss of money respectively. The result of that computation for losses was then subtracted from that for gains, resulting in the expected utility of that choice. For example, a square associated with a 90% chance of a gain of $5.00 (and a

10% chance of a loss of that amount) would yield an expected utility of [0.9*5]-[0.1*5] = 4. One associated with a 65% chance of a gain of $5.00 (and a 35% chance of a loss of that amount) would have an expected utility of [0.65*5]-[0.35*5] = 0.8. In this way, a spectrum of nine expected utilities was generated (one for each non-neutral member of the set of stimuli) that ranged from positive to negative four.

This information was highly useful an analysis of participants' choice behavior. Another major contrast of interest involved a comparison of choice behavior on the choice tasks, before alteration of the contingencies, with the reversal learning and reversal preference tasks. Measures of reversal learning, or how well an individual employs the new contingencies associated with the visual stimuli in the final reversal choice task, were especially useful. Such measures provided important information how acute stress affected individuals' ability to acquire instrumentally conditioned responses that can guide subsequent decisions-making under acute stress.

Skin conductance levels (SCL) were recorded on the second day of the experiment only. Prior to each of the three day 2 tasks, participants were asked to fixate on a point on a computer screen for two full minutes (during which SCL was measured). The third of these fixations took place while participants' hands were immersed in cold or room temperature water – allowing for a comparison of SCL before and during the administration of no stress or acute stress. Acquisition of SCL data was performed in accordance with those guidelines presented in Chapter 2. Additionally, participants completed two questionnaires at the end of the experiment. One was a post-experimental questionnaire asking participants to rate their experience of the experiment (including their subjective experience of the cold pressor task) on a 7-point Likert Scale. The

second measured risk-preferences in financial decision-making situations, based on the work of Holt & Laury (2002).

3.3 Results

Behavioral Measures: Learning Phases

Reaction time data were analyzed for the initial two blocks of learning trials on Day 1 of the experiment. For this analysis, the squares were grouped by the valence of the dominant value attached to them (positive, neutral or zero, and negative) in order to examine any differences in behavior related to the valence of the reward value of the stimulus. A 2 (learning block: first vs. second) x 3 (value valence: positive vs. neutral vs. negative) repeated-measures ANOVA indicated that reactions times did not significantly differ by block, $F(1, 27) = 0.78$, $p = .37$, $\eta_p^2 = 0.028$, or the value of a stimulus, $F(1, 27) = 1.57$, $p = .22$, $\eta_p^2 = 0.055$. No significant interaction of learning block and stimulus value was observed, $F(1, 54) = 0.26$, $p = .78$, $\eta_p^2 = 0.009$. On average, participants responded well within the two second response period on Day 1 ($M = 816.33$, $SD = 174.59$).

Another similar 2 (learning block: original values vs. reversed values) x 3 (value valence: positive vs. neutral vs. negative) repeated-measures ANOVA was conducted to compare averaged reaction time data from Day 1 of the experiment with those from Day 2's learning task – where the contingencies of the squares were altered. Reactions times did not significantly differ by based on learning block, $F(1, 27) = 0.02$, $p = .89$, $\eta_p^2 = 0.001$, or valence of a square's value, $F(2, 54) = 0.83$, $p = .44$, $\eta_p^2 = 0.030$. No significant interaction of learning block and square value was observed, $F(1, 54) = 1.27$,

p = .29, η_p^2 = 0.045. Consistent with Day 1 performance, on average participants responded well within the two second response period on Day 2 – even with the new altered values. (M = 818.69, SD = 153.59). Thus, these data indicate a consistent pattern of reaction times regardless of the timing of a given learning task, the expected utilities of the stimuli, or alterations to the values with which the stimuli were associated.

Behavioral Measures: Choice Phases

In order to analyze the decisions participants made in the choice tasks of the task, a slightly different approach was taken with respect to the values of the stimuli. Rather than collapsing across positive, neutral, and negative value classes, in these analyses the expected utility of a given square served as an independent variable. This allowed participants' choices to be tested for linear relationships between choice and the relative worth of each member of the set of stimuli. Choices made when the control square was a member of the pairing in a given trial were excluded from the analysis. Finally, choices were also grouped based on whether or not the decision was a 'good' or 'bad' one based on the expected utilities of the stimuli in the pair. For example, choice of a square associated with an expected utility of 0.3 would be a 'bad' choice if it were paired with a one whose expected utility was 4 (because the latter would be more likely to result in a higher gain). Conversely, if paired with a square whose utility were -0.3 that choice would be a 'good' one.

For the initial three choice tasks, before reversal, a 3 (choice task block: 1 vs. 2 vs. 3) x 2 (choice quality: good vs. bad) x 9 repeated-measures (expected utility) ANOVA was performed on participants' choice data. A significant 2-way interaction was observed between block of the choice task and choice quality, $F(2, 54) = 5.93$, $p <$

.01, η_p^2 = 0.180 (see Figure 3.2). Within-subjects contrasts indicated that participants exhibited a learning-related linear increase in good choices (and therefore a decrease in bad ones) as they proceeded through the three choice tasks, $F(1, 27) = 9.7$, $p < .01$, $\eta_p^2 = 0.264$. Also supporting the proposal that participants learned the contingencies of the stimuli was an ordinal 2-way interaction, between choice quality and expected utility, $F(8, 216) = 276.50$, $p < .001$, $\eta_p^2 = 0.911$ (see Figure 3.3). According to within-subjects contrasts this highly significant interaction conformed to a linear pattern such that participants made increasingly more good choices as expected utilities became more positive and significantly fewer as they become more negative, $F(1, 27) = 1091.03$, $p < .001$, $\eta_p^2 = 0.976$. No significant 3- way interaction was observed.

When a new 2 (choice quality: good vs. bad) x 9 (expected utility) repeated-measures ANOVA was conducted on choice data from the reversal choice task on day 2, with stress as a between-subjects factor, a similar pattern emerged. Participants learned the contingencies of the stimuli, as evidenced by a 2-way interaction between choice quality and expected utility, $F(8, 208) = 157.49$, $p < .001$, $\eta_p^2 = 0.858$. As in the earlier choice tasks, within-subjects contrasts indicated that this interaction conformed to a highly linear pattern (see Figure 3.4). Participants made increasingly better choices as expected utilities became more positive and significantly worse as they become more negative, $F(1, 26) = 1639.33$, $p < .001$, $\eta_p^2 = 0.984$. Although there was no significant effect of stress as a between-subjects factor, $F(1, 26) = 0.36$, $p > .10$, $\eta_p^2 = 0.001$, a marginally significant 2-way interaction between choice quality and stress was observed, $F(1, 26) = 3.51$, $p = .07$, $\eta_p^2 = 0.119$. Post-hoc independent t-tests performed on the total number of good vs. bad choices for those participants under stress or no stress

confirm this marginal effect. Participants made fewer bad decisions under stress (M = 27.21, SD = 7.89) as compared to no stress (M = 31.86, SD = 6.33), $t(26) = -1.71$, $p = .10$, $d = -0.65$. Conversely, more good choices were made under stress (M = 43.29, SD = 6.64) as compared to no stress (M = 38.5, SD = 5.92), $t(26) = 2.01$, $p = .055$, $d = 0.76$. Also of great interest is that participants under acute stress chose the best square from the pre-reversal tasks (a 90% of gaining 5.00) significantly more often than participants under no stress, despite the fact that the square's value in the reversed set was $0.00, $t(26) = 2.22$, $p < .05$, $d = 0.84$. No significant effect of gender was observed in this experiment, $F(1, 26) = 2.54$, $p > .10$, $\eta_p^2 = 0.089$.

Post-experimental Measures

See Table 3.2 for a correlation matrix containing the central variables of interest in Experiment 4. An independent t-test performed on participants' answers to the post-experimental questionnaire indicated that the acute stress procedure resulted in subjective stress levels that were significantly higher than the no stress control chance, $t(26) = 4.09$, $p < .001$, $d = 1.55$. The results of the BIS/BAS survey did not significantly covary with participants' choice behavior in this experiment, nor did self-report ratings of subjective levels of stress resulting from the acute stress procedure.

3.4 Discussion

Participants were well able to acquire the contingencies associated with the square stimuli in the learning tasks, and use that information to guide decisions in the choice tasks of the current experiment. In addition, when presented with new values for the same stimuli participants who were exposed to acute stress utilized those values

somewhat more advantageously in decision-making that participants who remained unexposed to acute stress. Two different hypotheses were proposed. One held that participants under acute stress would fall back on automatized preferences established through the extensive training given during the initial two learning tasks. This effect would manifest behaviorally as a preference for specific squares, associated with the initial values, from the first two learning tasks. Another hypothesis was that acutely stressed individuals would exhibit enhanced instrumental conditioning of the new stimuli in the reversal task.

Evidence was found in support of both hypotheses. Acutely stressed participants chose the most valuable square from previous pre-reversal tasks more often than non-stressed individuals, even though it was worth nothing1. Tentative support was also observed in the case of the second hypothesis. Participants who were stressed made more good choices and fewer bad choices than unstressed participants on the final reversal choice task. Although statistically this was a marginal effect, it does indicate that stressed participants were able to acquire and use the new contingencies more completely those who remained unstressed. Thus, not only were stressed participants able to better acquire new instrumentally conditioned preferences under stress – they also maintained existing preferences and were more likely to use them to guide their decision-making.

Interestingly, the effects of stress on at this level may be dissociable by gender. In another line of research, using eyeblink conditioning in rats, it was discovered that intermittent shocks to the tail actually enhanced conditioned eyeblink responses in males (Shors et al., 1992). In contrast, experiments using a similar design with female rats provide evidence that conditioning of the eyeblink response is actually impaired (Wood

& Shors, 1998). Recent research also provides evidence that these effects generalize to humans, using fear conditioning paradigms. For example, Jackson *et al.* (2006) observed an identical pattern of enhancement of conditioned responses in males and impairment in females when exposed to even a mild acute stressor. Furthermore, another study indicates that these effects may be mediated by the effects of stress on the endocrine system and thus may further vary by individual reactivity to stress in that domain (Zorawski, Blanding, Kuhn, & LaBar, 2006). Taken together these lines of research support the hypothesis that gender and reactivity to stress play some role in acute stress effects on associative learning (for an in-depth review, see Sandi & Pinelo-Nava, 2007). Despite the predictions of this research, no significant gender effects were observed in the current experiment.

Although a number of experimental questions have been addressed in Chapters 1 and 2 of this manuscript, additional questions of central import to the topics that have been discussed remain unanswered. For example, exactly how does acute stress impair higher-order reason and promote reliance on lower-level automatized cognitions and behaviors at the neural level? Given that stress is a highly hormonal phenomenon, what is the involvement of the endocrine system in this phenomenon? In Chapter 4 an attempt will be made to address these open questions by having participants perform a financial decision-making task, similar to those presented in Chapter 2, during fMRI scanning. In addition, the stress hormone cortisol will be measured multiple times during the experiment to establish a timeline of hormonal reactivity to acute stress exposure.

Chapter 4

Experiment 5: The Neural Basis of Acute Stress and Decision-making Interactions

4.1 Introduction

The research presented in Chapters 1 and 2 indicates that exposure to acute stress of a sufficient intensity can result in either impairments or enhancements of performance, in a highly context dependent manner. One plausible hypothesis related to this observation is that acute stress facilitates more automatized types of information processing and behaviors. Cognitive faculties structured along a dual process framework would offer a distinct evolutionary advantage, in that an individual could better ensure their survival by being equipped to maintain organized and goal-directed behavior even when higher-order cognitive abilities are most likely to be compromised, as in the case of medium to high levels of stress. A dual process account would also explain why decision-makers exhibit different patterns of performance improvements or impairments under the influence of stress, depending on the type of task being engaged. This chapter will focus on elucidating the neural circuitry involved in a stress-related shift of decision-making from deliberative, conscious and effortful reasoning to reasoning of a more automatized, intuitive and effortless kind.

Before it is possible to directly address this question, however, it is important to develop an understanding of how the brain processes a class of information critical to the ability to set the goals that guide decision-making – reward-related information. To that end, processing of reward-related information and the general neuroanatomy of the brain's reward circuitry will be discussed. This will be followed by a review of fMRI research that has established a deeper understanding of the functional roles of the

components of the brain's reward circuitry and their involvement in decision-making. Finally, the chapter will conclude with an fMRI experiment designed to examine interactions between acute stress and financial decision-making at the neural level.

4.2 Reward Processing and Decision-making

As a goal-oriented behavior, decision-making is a process by which some choice is made (and usually an action initiated) to pursue an intended goal. If goals were not evaluated in accordance with some standard, however, a decision-maker would have no basis for choosing a specific course of action. One interpretation describes this aspect of decision-making in terms of the "hedonic man" – a characterization which states that the positive or negative hedonic content associated with outcomes of past choices, or predicted for future ones, guides decision-making (Wolfe, 2008). Therefore, before decisions can be made the brain must be able to process reward-related information to appraise the likely hedonic value of a goal.

Reward-related information can be broadly classified into two categories that may have opposite effects on decision-making. 'Rewards' can be operationally defined as positively valenced stimuli that can evoke exploratory or approach behavior (e.g., searching for food). Punishments, on the other hand, are stimuli of a negative valence that may evoke avoidance behavior (e.g., avoid foods that led to sickness). Thus, an individual's ability to process rewards and punishments enables him or her to navigate through the environment in a goal-directed manner – resulting in observable behaviors that involve being drawn to rewards and repelled from punishments. As such, reward processing is intimately related to decisions-making.

In order to process reward-related information, the brain must have some mechanism(s) by which value is computed. Complicating matters, however, is that 'value' is a concept with multiple dimensions. For example, an important distinction must be drawn between the value of a reward that has been experienced or *subjective value* (e.g., a sip of juice already consumed) and the value of a reward one expects to experience at some future point or *expected reward value* (e.g., a sip of juice not yet taken). Being able to learn about, and adapt to, an ever-changing environment requires an individual be able to compute representations of current and future goals – in addition to the ability to evaluate the outcomes of past actions. Thus, evaluative and predictive computations of rewards and punishments are essential to guide future decisions and enable decision-making to attain (and maintain) a goal-directed focus. The experiment presented in this chapter will specifically examine the manner in which acute stress might modulate establishment of the subjective value of rewards at the neural level.

4.3 Neural Circuitry of Decision-making: General Neuroanatomy

Recent fMRI research on the neural basis of decision-making builds upon a rich animal literature that has identified a constellation of regions involved in the processing of rewards, and reward-related learning, to guide behavior (for review, see Berridge & Robinson, 2003; Dickinson & Balleine, 1994; Haber, Kunishio, Mizobuchi, & Lynd-Balta, 1995; Robbins & Everitt, 1996; Rolls, 1999; W. Schultz, 2000; Wise & Hoffman, 1992). This 'reward circuitry' consists of a diverse array of subcortical and cortical regions which most prominently features distributed prefrontal regions, the basal ganglia (particularly the multifaceted striatum), and the amygdala – all modulated by

dopaminergic innervations from midbrain targets such as the substantia nigra and ventral tegmentum area. When considering fMRI research involving these regions it is vital to note that each region is anatomically and functionally complex, and can be subdivided along subtle dimensions that are difficult to highlight given the restraints imposed by the technology. In light of that fact, however, attempts have been made using fMRI to devise clear criteria for differentiating between the two (e.g., Breiter et al., 1997). The general neuroanatomy of these regions will be discussed first, followed by their functional roles

At the cortical level various loci within the prefrontal cortex (PFC) have been implicated as components of the brain's reward processing circuitry. A number of these regions interact to form a large functional network in humans and non-human animals, referred to as the orbital and medial prefrontal cortex (see Figure 4.1; Ongur & Price, 2000). It is important to note that this swathe of cortex is functionally heterogeneous, and exhibits connections with many and diverse brain regions. Within this larger network, the orbital prefrontal cortex (OFC) and medial prefrontal cortex (mPFC) have received a great deal of attention in the study of decision-making utilizing fMRI.

The anatomical boundaries between OFC and mPFC are somewhat blurred, in part because research indicates that they overlap (Kringelbach, 2005). Given the connectivity of these regions, and their integrative nature, a functional overlap is not necessarily surprising (for an extensive neuroanatomical review, see Ongur & Price, 2000). Located on the posterior, central and lateral orbital surface of the frontal lobe of the brain, the human OFC is roughly composed of areas 11, 13 and 47/12 (Ongur & Price, 2000). Involvement of this region in emotional processing and decision-making is based in part on its diverse connectivity (Rolls, 1999). These include, but are not limited

to, other PFC centers involved in cognitive control such as the dorsolateral prefrontal cortex (Carmichael & Price, 1995; Miller & Cohen, 2001), subcortical regions such as the amygdala (Amaral & Price, 1984) and striatum (Eblen & Graybiel, 1995), and multimodal sensory input from primary cortical regions (Carmichael & Price, 1995). Thus, OFC is well-placed and connected to modulate behavior by integrating sensory, emotional and cognitive information (for a review and meta-analysis, see Kringelbach & Rolls, 2004).

The neighboring mPFC has also been implicated in monitoring the outcome of decisions, especially with respect to processing of social information (Amodio & Frith, 2006). This may overlap some medial portions of cortex on the orbital wall, obscuring a clear-cut anatomical boundary between mPFC and OFC (Kringelbach, 2005). For example, mPFC has been defined as including parts of the areas just described with respect to OFC (medial 11, anterior 13, and orbital 47/12). The medial network also includes areas 14, 24, 25 and 32 on the medial wall of the frontal lobe (Ongur & Price, 2000). Regardless of the specific boundaries of this region, what is clear is that these mPFC areas innervate numerous visceromotor regions (Ongur & Price, 2000) – perhaps in complement to the connections of the more sensory OFC, hearkening back to the aforementioned theory that these two regions form a single functional network.

Regions in the PFC are interconnected with subcortical structures involved in motor, cognitive and motivational components of behavior – chiefly the basal ganglia. The connectivity between different loci within the striatum, the input unit of the basal ganglia, and various cortical sites gives rises to a vast array of ‘corticostriatum’ loops integral in mediating the aforementioned aspects of goal-directed behavior (Alexander &

Crutcher, 1990; Balleine, Delgado, & Hikosaka, 2007; Middleton & Strick, 2000). The striatum is composed of three structures: the caudate nucleus, putamen and nucleus accumbens. A dorsal/ventral distinction has been suggested for the striatum on functional grounds (see Carmichael & Price, 1995; O'Doherty et al., 2004; Robbins & Everitt, 1996) with some support from anatomical studies. The dorsal striatum, consisting of the caudate and putamen, primarily connects with prefrontal regions involved in cognition and motor functions, while the ventral striatum, including the nucleus accumbens and more ventral portions of the putamen and caudate (Fudge & Haber, 2002; Haber, Kim, Mailly, & Calzavara, 2006), is largely connected to ventral prefrontal and limbic regions thought to be involved in motivation and emotion respectively (Groenewegen & Uylings, 2000). Rather than a dorsal/ventral divide, however, an alternative proposal suggests that information flow within the striatum may follow a medial to lateral gradient that subserves the initial acquisition of reward-related associations to habit formation (Haber, Fudge, & McFarland, 2000; Voorn, Vanderschuren, Groenewegen, Robbins, & Pennartz, 2004).

The aforementioned corticostriatal loops are innervated by dopaminergic neurons from midbrain nuclei, with the ventral striatum receiving inputs being mainly from the ventral tegmentum area and dorsal striatum from the substantia nigra. Early work in non-human primates lead to the theory that the excitatory neurotransmitter dopamine plays an important role in reward processing (for a review, see W. Schultz, 2007). Specifically, dopaminergic neurons respond to unexpected rewards and conditioned stimuli that signal a potential reward, further being depressed at the omission of an expected reward. These findings have led to the theory that dopamine neurons are highly involved in goal-

directed behaviors and therefore decision-making (Wolfram Schultz, Dayan, & Montague, 1997).

An additional subcortical region that has received much attention in fMRI studies of reward-processing is the amygdala. Consisting of a cluster of interconnected subnuclei near the anterior portion of the temporal lobe, the amygdala is a region previously implicated in processing emotional information, particularly fear, as well as stress (Davis, 1992; Delgado, Olsson, & Phelps, 2006; Gray & Bingaman, 1996; LeDoux, 2000; Morris et al., 1998). It receives lower-level thalamic sensory input as well as interoceptive input from visceral sensory relays, the hypothalamus and higher-level sensory cortical regions such as OFC, as well as exteroceptive information via cortical association areas and the thalamus (Derryberry & Tucker, 1992). Most relevant to the current experiment is that the amygdala has been observed to be highly involved in the stress-related modulation of fear conditioning (Akirav & Maroun, 2007). Although it is clear the amygdala does aid in the detection of threatening situations and triggering of an appropriate behavioral response, this area also plays a role in the stress response (Morris *et al*., 1998).

4.4 Functional Neuroanatomy of Decision-making: OFC and mPFC

Numerous fMRI studies provide evidence that corticostriatal circuits (particularly those connecting the OFC and the striatum) play a role in coding for the subjective value of a stimulus, across a wide range of modalities and types of reinforcers. In terms of outcome evaluation, for example, OFC activation has been observed during delivery of affectively pleasant compared to aversive gustatory stimuli (glucose vs. salt respectively;

O'Doherty, Rolls, Francis, Bowtell, & McGlone, 2001), with similar results observed in the olfactory domain (Rolls, Kringelbach, & de Araujo, 2003). Other such studies support the proposal that OFC is involved the representation of a stimulus' reward value in the domains of somatosensation (Rolls, O'Doherty et al., 2003), and more subjective modalities such as audition (Blood, Zatorre, Bermudez, & Evans, 1999) and vision (O'Doherty et al., 2003). The results of sensory-specific satiation studies, where hungry participants are presented with food-related stimuli and then fed one type until satisfied, provide additional evidence in this direction. When individuals in that context are exposed to a conditioned stimulus predicting a satiated food, OFC exhibits decreases in blood-oxygen-level-dependent (BOLD) signal associated with the devaluation of that food post-feeding (Kringelbach, O'Doherty, Rolls, & Andrews, 2003; O'Doherty et al., 2000).

A neighboring prefrontal region, mPFC, may also be involved in coding for the value of rewards. One study observed BOLD activation increases in mPFC when participants received an anticipated reward (Knutson, Fong, Bennett, Adams, & Hommer, 2003). It has also been proposed that mPFC is involved in the computation of appetitive 'goal values' (the predicted subjective value of a reward contingent on some action; Hare, O'Doherty, Camerer, Schultz, & Rangel, 2008). While medial portions of OFC have also been implicated in processing of goal values (Rangel, Camerer, & Montague, 2008), the aforementioned difficulty in distinguishing a clear functional and anatomical boundary between OFC and mPFC leaves such assertions open to interpretation. Research in non-human primates does indicate, however, that a distinction of this type is appropriate in that corticostriatal projections to these two regions may be functionally organized the

lines of a dissociation established within the subcortical striatum (Ferry, Öngür, Xinhai, & Price, 2000; O'Doherty et al., 2004).

4.5 Functional Neuroanatomy of Decision-making: Dorsal and ventral striatum

The striatum is another brain region implicated in subjective value coding (see Knutson, Delgado, & Phillips, 2008 for a review). In terms of outcome evaluation, early studies suggested involvement of both dorsal and ventral striatum irrespective of type of reinforcer. For example, Delgado et al. (Delgado, Nystrom, Fissell, Noll, & Fiez, 2000) observed differential responses in both dorsal and ventral striatum in response to feedback granting monetary rewards, compared to monetary punishments or losses. Similar patterns in striatum BOLD signals have been observed with primary reinforcers ranging from beautiful faces (Aharon et al., 2001) to more gustatory rewards and punishments (O'Doherty et al., 2000; Small et al., 2003).

The role of the striatum in coding subjective value is also displayed in paradigms where a conditioned cue signals a potential reward. In such studies, the representation of the subjective value of a potential reward is recorded by a conditioned stimulus, at times influencing future decision-making. Increases in BOLD signal in the striatum are often reported in such paradigms using various types of reinforcers (O'Doherty, 2004). For instance, dorsal and ventral striatum activation correlates with cues that predict monetary rewards contingent on a rapid response (Delgado, Stenger, & Fiez, 2004; Kirsch et al., 2003; Knutson, Adams, Fong, & Hommer, 2001), as well as correlating with cues that predict juice rewards (O'Doherty, Deichmann, Critchley, & Dolan, 2002).

One important functional distinction between dorsal and ventral striatum that has been proposed in such conditioning paradigms and others suggests that subjective value representations may be coded with respect to task requirements. Specifically, the dorsal striatum has been linked primarily with appetitive conditioning paradigms that require an action component (response-reward associations) a function it is well-suited for due to its connections with motor and dorsal prefrontal cortices (Alexander & Crutcher, 1990), while the ventral striatum appears to be critical to creating stimulus-reward contingencies (see Balleine & Dickinson, 1998 for review of relevant animal data; Packard & Knowlton, 2002; Robbins & Everitt, 1996). Given the role of both regions is associative learning and conditioned behaviors, they are likely candidates for modulation of decision-making via acute stress.

In support of a dorsal/ventral distinction, a contingency between motivation and action has been found to correlate with BOLD signals in the human dorsal striatum. Tricomi and colleagues (Tricomi, Delgado, & Fiez, 2004) used an oddball like paradigm to attempt to explain previous results linking striatum and reward processes (Delgado et al., 2000). It was suggested that differential responses between reward and punishment outcomes previously observed in the dorsal striatum could be explained by the perception of control inherent in the experimental design. Participants receiving non-contingent delivery of rewards and punishments (masked as oddballs) did not recruit dorsal striatum activation. Instead, the dorsal striatum response to rewarding outcomes was only observed when a contingency existed between behavior and reward (via a response that was perceived to lead to the desirable outcome). This study and others (Elliott, Newman, Longe, & William Deakin, 2004; O'Doherty et al., 2004; Zink, Pagnoni, Martin-Skurski,

Chappelow, & Berns, 2004) indicated that the dorsal striatum was involved in the processing of the reinforcement of an action, rather than the reward per se.

In another study, O'Doherty and colleagues (2004) further suggested that the human dorsal striatum plays the role of an "actor", maintaining information about response-reward associations to enable better choices in the future, while the ventral striatum serves as the "critic" and predicts future rewards. This study employed two yoked conditioning tasks where participants made choices between stimuli predicting delivery of a juice reward or neutral solution at high and low probabilities (instrumental conditioning), or simply indicated which stimulus the computer had selected for them (classical conditioning). In accord with ideas put forth by actor-critic models (Barto, 1996; Sutton & Barto, 1998) it was observed that BOLD activity in a dorsal striatal "actor" correlated with prediction error signals particularly during the instrumental task. The ventral striatal "critic", on the other hand, demonstrated this relationship during both tasks. These results provide support for the proposition that dorsal and ventral striatum interact to guide behavior, by establishing a link between dorsal striatum and instrumental conditioning (the role of the actor) and ventral striatum and both instrumental and classical conditioning (critic). Thus, it is highly probably that these two regions work together to enable cognitions and behaviors to become automatized over time.

4.6 Functional Neuroanatomy of Decision-making: The amygdala

The amygdala's role in coding subjective value is prominent mostly in the domain of aversive processing. Specifically, the amygdala has been implicated as an "emotion"

structure given its involvement in fear conditioning paradigms (see LeDoux, 2000 for a review). Amygdala-related findings from a rich animal literature extend to humans, as amygdala activation has been found to correlate with conditioned stimuli that predict aversive outcomes (LaBar, Gatenby, Gore, LeDoux, & Phelps, 1998; Morris, Ohman, & Dolan, 1999; Phelps et al., 2001) and patients with amygdala lesions are unable to acquire fearful responses (as measured by skin conductance responses; LaBar, LeDoux, Spencer, & Phelps, 1995). Thus, it may be that the amygdala adaptively codes for subjective value of potential threat to build affective evaluations of environment, others and context (Petrovic, Kalisch, Pessiglione, Singer, & Dolan, 2008).

While studies across species support a role for the amygdala in learning about negative stimuli, both positron emission tomography (Hamann, Ely, Grafton, & Kilts, 1999; Royet et al., 2000) and fMRI (Dolcos, LaBar, & Cabeza, 2004) studies link the amygdala with positively valenced stimuli involved in appetitive or reward learning. Based on results of this type, it has been argued that the amygdala actually codes for intensity, rather than valence of an affective stimulus, and negative stimuli used in conditioning studies (e.g., shock) are typically more intense than positive ones (e.g., a pellet of food). For example, one study (Anderson et al., 2003) capitalized on the nature of olfactory stimuli to dissociate the contributions of valence and intensity (of a stimulus) to the subjective value of rewards. It was observed that, while BOLD activity in OFC was associated with valence of an olfactory stimulus, the amygdala exhibited a pattern of activation associated with intensity alone.

4.7 The Neural Architecture Underlying Stress and Decision-making Interactions

As discussed in Chapter 2, stress exerts a noticeable influence over cognition in general. It can modify cognitive functions in humans, including working memory (WM) systems (e.g., Patil et al., 1995). Proper functioning of WM, however, may be necessary but is not sufficient for sound decision-making capabilities. In fact, research indicates that the neural substrates of WM processes are dissociable from those supporting decision-making within the prefrontal cortex (Bechara, Damasio, Tranel, & Anderson, 1998). Although the neural architecture for these two systems functionally interact, they must be independent to some degree. Because of its close connections with sensory areas as well as reciprocal connections with most limbic areas including the amygdala, OFC is well placed to integrate information from reward and emotional processing (Kringelbach, 2005). Given its close connection to the basolateral amygdala, it is well suited to playing a role in goal directed behavior (Rolls, 1999). However as part of PFC, both OFC and lateral PFC are subject to the neurochemical changes engendered by stress.

The hypothesis that acute stress exerts a significant influence over decision-making is supported by neural data from rats, non-human primates, and humans (Arnsten, 1997; Arnsten & Goldman-Rakic, 1998; Herman et al., 2003). This platform of past research documents a relationship between the neurochemistry of the stress response and higher cortical areas. Animal research indicates that prefrontal cortex is a major target for neurochemical changes related to the cascade of effects associated with the stress response (Brown et al., 2005) and that the amygdala (rich in receptors for the stress hormone cortisol) may serve as an intermediary for this interaction (McDonald, 1991). The amygdala has recently been observed to be sensitive to the framing of a decision (De

Martino, Kumaran, Seymour, & Dolan, 2006). As such, it is particularly well suited as region of interest in research on stress and decision-making interactions.

Acute stress exposure sets off a cascade of responses that mediate PFC systems at physiological and cognitive systems levels. Evidence suggests that the amygdala is highly involved in the initiation of this cascade. Subsequent to activation of the HPA axis under acute stress, excessive release glucocorticoids and catecholamines within PFC may lead to a "hyperdopaminergic" response (Arnsten, 1997). Specifically, high PFC dopamine levels couple with protein kinase A (PKA) via G proteins and/or protein Kinase C (PKC) via calcyon (Arnsten, 2007). This coupling may serve to synergistically impair intracellular PFC signaling mechanisms. These neurochemical changes (and others possibly including norepinephrine and PKC) in PFC signaling and neurotransmission during periods of stress may compromise PFC functions, thus affecting cognition and behavior (Arnsten, 1997). OFC is anatomically connected to dorsal LPFC, and the two areas receive inputs from the same stress-related neural areas (amygdala) (Kringelbach, 2005). Therefore, it is likely that the effects of this "hyperdopaminergic" response, mainly examined in the context of WM research, generalizes to PFC-based decision-making as well.

The goal of the current experiment was to study how acute stress interacts with task-related activity in these diverse neural regions known to be involved in reward-related processing and decision-making. To that end, participants engaged in a financial decision-making task during fMRI scanning under conditions of acute stress and no stress. In order to confirm the efficacy of the stress manipulation, measures of skin conductance as well the stress hormone cortisol were acquired. Finally, individual

differences in risk-preference and self-regulatory abilities will be probed via the administration of a battery of post-experimental surveys designed to tease apart those complicated factors.

Based on work by Delgado (2007) it is known that striatal reward circuits differentiate between positive and negative feedback. In addition, other research has shown that glucocorticoid (i.e. cortisol) release subsequent to acute stress exposure results in increased dopamine release in the ventral striatum (Wand et al., 2007). Therefore, it is hypothesized that acute stress will modulate reward-processing (and therefore decision-making) at the striatal level. Furthermore, research indicates that the amygdala may mediate susceptibility to the effects of framing in that increases in amygdala activity have been associated with increased reflection in the strategy choices of participants (De Martino et al., 2006). The effects of stress on BOLD-related changes in amygdala activity will also be examined, with the specific hypothesis that this region will show increased activity under stress. Finally, based on research in non-human primates indicating that PFC can be brought "offline" under acute stress (Arnsten & Goldman-Rakic, 1998), it is hypothesized that PFC activity will be significantly altered under acute stress.

4.8 Method

Participants

Twenty-three individuals participated in the current experiment (11 females, 12 males, mean age = 21.3 years, SD years = 3.05). Participants responded to an IRB approved advertisement, which explained the general nature of the study and indicated

that participants would be compensated for their time at the rate of $25 per hour. In addition, participants were told that they would receive compensation based on their performance, namely the summed outcomes of one random gamble from each block. Additional compensation ranged from $0 - $6.00. A twenty-fourth participant was excluded from data analysis due to extreme head motion.

Procedure

Participants completed four blocks comprised of (a) a relaxation technique involving mental visualization, (b) exposure to acute stress or a no-stress control procedure, and (c) a financial decision-making task (similar in design to the experiment presented in Chapter 2). The relaxation technique was performed prior to the stress induction procedure, which in turn occurred immediately before each block of the financial decision-making task. All participants completed two blocks of the task under no stress and two under stress for a total of four blocks in all. In order to control for the circadian rhythm of salivary cortisol levels, all experimental sessions took place between the hours of 2 and 6 pm. In addition all participants came in to the lab at the same time of day as their scheduled MRI appointment, prior to the scan itself, to complete paperwork and undergo a short introduction to the relaxation and financial decision-making tasks. During this session, baseline SCL readings were taken as well as a baseline cortisol sample.

Relaxation Task

In order to allow participants the opportunity to recover from stress exposure, they were asked to perform a relaxation task at specific times during their scanning session. Use of this task was intended to enable participants to return to a baseline level

of stress activity post-stress, in the hopes of preventing later blocks of experimental task from being contaminated by stress when not called for by the experiment's design. Note that functional data were not acquired during performance on this task. At the introductory meeting prior to the MRI scan, the investigator asked participants to choose a relaxing and neutral scene (e.g., a calming walk through the park). It was made clear that this scene must not involve anything exciting or intensely emotional. During the experiment itself participants alternated between envisioning the scene for 45 seconds and simply focusing on a crosshair for 30 seconds in three cycles, resulting in a total relaxation task time of 3 minutes and 45 seconds. This task was performed prior to the stress induction procedure and financial decision-making task of each block, for a total of four times.

Stress Induction

Regulations preventing the use of water in the same room as the magnet restricted application of a traditional cold pressor, so an alternative was devised. An "arm wrap" was created from a combination of MRI compatible dry gelpacs which, when cooled to freezing, remained at a temperature of approximately 4º C. Although pilot testing indicated that this device did in fact cause stress as measured by skin conductance rates, one concern was that it was inherently different from the traditional cold pressor experience in that the surface area of participants' hand could not be fully exposed to the stressor as would occur when fully immersing a hand in water. In order to account for this the arm wrap extended up the forearm to just below the elbow, thus allowing additional surface area to be exposed to the stressor.

Administration of this procedure before the second and fourth blocks of financial decision- making tasks comprised the "stress" condition. A no-stress control condition involved covering the participants' arms in a similar wrap created from towels (at room-temperature). The no-stress control procedure was administered twice prior to the first and third blocks of the financial decision-making task. Thus, the order of presentation of the blocks of trials conformed to the following pattern: no stress, stress, no stress, stress. In this way, it was ensured that at least two blocks of functional data (blocks 1 and 2) would be available for analysis without the participant having already been exposed to stress – which might influence the results of later blocks.

Financial Decision-making Task

Participants were presented with a gambling task very similar to the one presented in Chapter 2. This task involved a choice between two alternatives of equal expected value, but varied probability. On a given trial, both choices were presented in either the loss or gain domain: a possibility to "lose" or to "win" money respectively. One concern that arose from Experiment 1, however, was that participants found repetition of the same set of four gambles to be boring and extremely hard to focus on. Therefore, the task was adapted in order to provide additional variety in the types of gambles presented, further engaging participants in the task.

While in essence the same sets from Experiment 1 were used with respect to the probability associated with each choice, one notable change was made with regard to the dollar amounts attached to each. In Experiment 1 each percentage was associated with a specific dollar amount and therefore yielded one specific expected value (EV). For example one decision might be between an 80% chance of losing $0.75 or a 20% chance

of losing $3.00, in which both choices have an EV of 0.80 X 0.75 = 0.6 (conversely 0.20 X 3.00 = 0.6). In the current experiment, dollar amounts were further varied by 0.1 EV above and below the 0.6 level used in Experiment 1 while holding probability constant (see Table 4.1). To build on the example already provided in the case of 0.1 above an EV of 0.6, another varied trial might involve a choice between an 80% chance of losing $0.87 or a 20% chance of losing $3.48, in which both choices have an equivalent EV of 0.80 X 0.87 = 0.7 (conversely 0.20 X 3.48 = 0.7). Finally, for trials varied to be 0.1 below an EV of 0.6, the choice would be between an 80% chance of losing $0.63 or a 20% chance of losing $2.52, in which both choices have an EV of 0.80 X 0.63 = 0.5 (conversely 0.20 X 2.52 = 0.5). Thus while within a trial EV was always held constant, between trials EV fluctuated between 0.5, 0.6, and 0.7. These additional gambles were created in order promote participants' engaging more fully in the task.

As in Experiment 1, gambles were presented in both the loss and gain domains. In order to gain increased power for data analysis purposes, data from the sets were collapsed within a domain (loss or gain). Stimuli were counterbalanced for order of presentation, and side of the screen each choice was presented on. There were a total of 96 gambles presented over the entire experiment; 48 per stress condition (i.e. both no-stress X both stress blocks combined). Within a stress condition, 24 trials were presented in the loss and 24 in the gain domain. Furthermore, within a domain 12 gambles were from the first set (80/20%) and 12 were from the second set (60/40%). Finally, with respect to the new varied gambles each dollar amount appeared 2 times within a stress condition (once in each block).

Participants had 4s to process the stimulus and make a decision, followed by a jittered inter-stimulus interval between 10 and 14 seconds. They were then presented with feedback based on their choice for 2s, followed by a jittered inter-trial-interval also between 10 and 14 seconds. Feedback, which accurately reflected the probability associated with each choice throughout the experiment, was presented as a confirmation of the dollar amount of their loss or gain. If no loss or gain occurred, participants were simply presented with a statement that they lost (or won) $0.00.

Salivary Cortisol Sampling

In order to acquire measurements of salivary cortisol, participants were asked to lightly moisten a cotton-like material (salivette) in their mouths for about one minute. Upon completion of this procedure, the subject withdrew the salivette and the experimenter immediately placed it in its individual centrifuge tube. Seven samples were acquired for each participant. The first was acquired during the introductory session (previously described) prior to the scan itself, while six other sample collections were interspersed throughout the scanning session. These occurred in approximately 15 to 17 minute intervals, with the second taken just prior to insertion into the magnet. A third sample was taken after 15 minutes of anatomical scans at the beginning of the experiment, while subsequent samples (4 through 7) were taken immediately after each financial decision-making task functional scan.

At the end of each day, samples were frozen in cold storage at -10º C. When a sufficient number of samples had been acquired (after about one month) they were packed with dry ice and sent to Salimetrics Laboratory (State College, PA) for duplicate biochemical assay analysis. It should be noted that cortisol, even when present in saliva,

is an extremely stable compound and can be stored without degradation of the sample at 5º C for at least three months (Garde & Hansen, 2005).

Behavioral and Post-experimental Measures

As in Chapter 1, choosing the option associated with a lower probability of occurring was considered a "risky" choice, while choosing the higher probability option was deemed a "conservative" choice. This framework allowed us to probe the interaction between the variables of interest in the experiment: (a) individuals' physiological state (No-stress x Stress), (b) the decision domain (Loss x Gain), and (c) participants' chosen decision-making strategy (Risky x Conservative) on a given trial. Reaction time was recorded for choices made in the financial decision-making task.

Skin conductance levels (SCL) were recorded during performance on the financial decision-making tasks of each block. SCL data were collected and analyzed in accordance with the procedure described in Chapter 2. Participants completed four questionnaires at the end of the experiment, in order to establish individual difference factors that might explain subsequent behavioral performance (as well as task-related changes in fMRI signal). One was a post-experimental questionnaire asking participants to rate their experience of the experiment (including their subjective experience of the cold pressor task) on a 7-point Likert Scale. The second, known as the penny game, was intended to measure risk-preference in financial decision-making situations based on the work of Holt and Laury (2002). The third was the Emotion Regulation Questionnaire (ERQ) designed by Gross & John (2003). It was believed that the ERQ might be useful in apportioning between-subjects variability with respect to how well an individual was able to reappraise or suppress their reaction to the acute stressor, and maintain organized

behavior. The fourth was the BIS/BAS, a survey which measures participants' sensitivity to aversive (BIS) versus rewarding (BAS) information and stimuli (Carver & White, 1994).

fMRI Acquisition and Analysis

Imaging was performed on a 3T Siemens Allegra scanner equipped with a fast gradient system for echoplanar imaging. A standard radiofrequency head coil with foam padding was used to restrict participants' head motion while minimizing discomfort. High-resolution axial images (T1-weighted MPRAGE: 286 x 256 matrix, FOV = 256mm, 176 1mm axial slices) were obtained from all subjects. Functional images (single-shot gradient echo EPI sequence; TR = 2000ms; TE = 25ms; FOV = 192cm; flip angle = 80º; matrix = 64 x 64; slice thickness = 3 mm) were also acquired during performance on the financial decision-making tasks. In addition, thirty-five contiguous oblique-axial slices (3 x 3 mm^3 voxels) oriented parallel to the anterior commissure-posterior commissure line were obtained. Data were then preprocessed and analyzed using BrainVoyager software. Preprocessing involved motion correction (six-parameter, three-dimensional motion correction), spatial smoothing (4-mm FWHM), voxel-wise linear detrending, high-pass filtering of frequencies (3 cycles per time course) and normalization to Talairach stereotaxic space (Talairach & Tournoux, 1988). An event-related design was employed.

A single random-effects analysis was performed on functional data for the stimulus presentation/response and feedback phases of the financial decision-making task. Based on this analysis a general linear model (GLM) was defined in which a number predictors were regressed onto the dependent variable of blood-oxygen-level

dependent changes within the brain. Eight predictors were entered for the stimulus presentation/response period of the financial decision-making task including: the domain of the trial (loss or gain) by each of the two possible strategy choices a participant could have made (risky or conservative) by the stress condition of the block of trials (acute stress or no-stress control). The feedback phase of the task was modeled using sixteen regressors: the domain of the trial (loss or gain) by the type of feedback provided (gain, loss, no-gain, no-win) by the stress condition of the block of trials (acute stress or no-stress control). Motion parameters generated during fMRI data preprocessing were included as covariates of no-interest (to control for head motion), as were portions of fMRI data resulting from missed trials. This resulted in a GLM involving 32 predictors, 8 of which were of no-interest.

Imaging results were acquired by creating regions of interest (ROI) based on a contrast between BOLD activation changes associated with all feedback that had a positive valence ("Win" or "No Loss") versus a negative one ("Loss" or "No Win" trials). Given a priori ROIs previously defined by a similar contrast in other (for review, see Delgado, 2007), it was thought that this contrast would best highlight task-related alterations in BOLD signal in regions of the brain known to be involved in reward processing and decision-making. These ROIs were established at two levels of statistical significance. First, the right caudate ROI was set at a Bonferroni corrected threshold of $p = .05$. This level of correction, although very strict, was necessary given the spatial extent of the ROI. Second, corticostriatal regions previously involved in affective learning and decision-making including: the left caudate, left and right putamen, left and right anterior cingulate cortex (ACC), left and right OFC, left ventrolateral PFC (VLPFC)

and two left parietal regions, at a less conservative threshold of $p < .001$ (uncorrected). In addition, one ROI in the right amygdala was established via a 2 (stress condition: no stress vs. acute stress) x 2 (decision domain condition: loss vs. gain) x 2 (strategy choice: risky vs. conservative) analysis of covariance performed on data from the stimulus/response portion of task trials. This exploratory analysis was conducted a liberal threshold of $p < .01$ (uncorrected). In order to limit the extent of BOLD activation examined in each ROI, parameter estimates for each predictor were extracted only from those active voxels surrounding the peak voxel in a cluster, with a maximum cluster spread of 6 x 6 x 6 voxels. After extraction, parameter estimates for both the stimulus/response and feedback periods of the task were analyzed to examine stress- and task-related changes in BOLD activation.

4.9 Results

Behavioral and Post-experimental Measures

A paired t-test was performed on participants' average level of SCL in microsiemens (μs) for all data points in each combined stress condition (Blocks 1 and 3 vs. Blocks 2 and 4) for the stimulus/response and feedback periods of the behavioral task. This test revealed no significant difference in SCL between the acute stress and no-stress conditions in the stimulus/response, $t(22) = 0.79$, $p > .10$, $d = 0.57$, or feedback periods, $t(22) = 0.92$, $p > .10$, $d = 0.58$. Participants' answers to the post-experimental questionnaire did, however, indicate that the cold arm wrap resulted in subjective stress levels that were elevated significantly above those experienced during the no-stress control procedure, $t(23) = 11.13$, $p < .001$, $d = 3.82$. To further address this issue a paired

t-test was performed, comparing 16 participants' average level of salivary cortisol (in micrograms per deciliter or µg/dL) in the no stress (blocks 1 and 3) versus acute stress (blocks 2 and 4) conditions. Participants did exhibit higher levels of cortisol in the stress (M = 0.21, SD = 0.14) as compared to no stress (M = 0.16, SD = 0.10) conditions, $t(15) = 2.73$, $p < .05$, $d = 0.44$. Although the skin conductance data do not indicate that participants were significantly stressed by acute stress exposure, both self-report and cortisol data support the interpretation that the stress manipulation was effective. Furthermore, the noise created by the MRI itself can interfere with measurements of skin conductance.

As in Chapter 2, a 2 (stress condition: no stress vs. acute stress) x 2 (decision domain condition: loss vs. gain) repeated-measures analyses of variance (ANOVA) was conducted on the proportion of risky strategy choices made by each participant to examine the effect of acute stress on our financial decision-making paradigm. Participants' choices with respect to decision-making strategy were computed as the proportion of times a participant made risky or conservative choices in each stress X decision domain condition compared to the total number of available choices. As was mentioned in Chapter 2, data analysis was conducted on risky strategy choices only because these data were proportional and sum to one (see Figure 4.2).

A significant main effect of decision domain was observed, $F(1, 22) = 10.29$, $p < .05$, $\eta_p^2 = 0.319$, such that individuals made more risky choices in the loss (M = 0.63, SD = 0.23) as compared to gain (M = 0.32, SD = 0.29) domain overall. Thus, as posited by Prospect Theory a reflection effect was observed in participants' decision-making strategies. A post-hoc paired t-test indicated that in the no-stress control condition,

participants made significantly more risky choices in the loss domain (M = 0.60, SD = 0.31) and therefore reciprocally fewer risky choices in the gain domain (M = 0.30, SD = 0.23), $t(22) = 3.16$, $p < .01$, $d = 1.12$. A reflection effect was also present within the stress condition for both loss (M = 0.65, SD = 0.30) and gain (M = 0.34, SD = 0.25) domain trials, $t(22) = 3.02$, $p < .01$, $d = 1.13$. In contrast to the results of Experiment 1 no significant interaction between stress and decision domain was observed, $F(1, 22) = 0.02$, $p > .10$, $\eta_p^2 = 0.001$. A main effect of stress exposure was observed, $F(1, 22) = 7.23$, $p < .05$, $\eta_p^2 = 0.247$. Participants reliably made more risky decisions regardless of whether the trial was framed as a loss or a gain under the influence of acute stress (M = 0.50, SD = 0.12) as compared to no stress (M = 0.45, SD = 0.14). See Table 4.2 for a correlation matrix containing the central variables of interest in Experiment 5.

As was mentioned earlier, a set of post-experimental questionnaires were administered to enable these data to be analyzed for individual differences in risk-taking and sensitivity to reward-related information. To that end, each was included as a covariate in the repeated-measures ANOVA just discussed. Neither the penny game, which measured risk-preferences, nor the emotion regulation questionnaire, which measured the ability to reappraise or suppress emotional information, significantly covaried with participants' choice data. However, the BIS/BAS proved to be of interest in this context. A marginally significant effect indicated that participants' BIS (behavioral inhibition) scores covaried with the stress and decision domain conditions, $F(1, 22) = 3.88$, $p = .062$, $\eta_p^2 = 0.147$. With BIS scores entered as a covariate the significance of a stress by decision domain interaction increased to a marginal effect from a prior significance level of $p = .834$, $F(1, 22) = 3.62$, $p = 0.71$, $\eta_p^2 = 0.147$.

In order to tease apart the influence of this individual differences factor on the results of the experiment two moderated multiple regressions were performed, on loss and gain domain risky strategy choice data separately, as for Experiment 1 in Chapter 2 (see Table 4.3). In the gain domain, the first order model without a Stress Condition x BIS interaction term did not attain significance, $R^2 = 0.018$, $F(2, 43) = 0.39$, $p = .68$. This was also the case for the second order model examining the interaction, $\Delta R^2 = 0.015$, $F(1, 42) = 0.65$, $p = .43$. In the loss domain, the first order model did not reach significance, $R^2 = .029$, $F(2, 43) = 0.64$, $p = .53$. The second order model in the loss domain regression was insignificant as well, $\Delta R^2 = .005$, $F(1, 42) = 0.23$, $p = .64$. Thus, these analyses were unable to tease apart differences in participants' strategy choices based on individual differences originating in the BIS scale – perhaps due to a lack of power.

4.10 fMRI Results

Please see Table 4.3 for a summary of coordinates, voxel counts and significance thresholds for all ROIs discussed in this section. Parameter estimates from each ROI, associated with both the stimulus/response and feedback portions of the experiment, were analyzed via multiple 2 (stress condition: no stress vs. acute stress) x 2 (decision domain condition: loss vs. gain) x 2 (strategy choice: risky vs. conservative) repeated-measures ANOVAs.

Striatal Regions of Interest: Caudate and Putamen

Turning to the stimulus/response period first, four striatal regions of interest were defined: right and left caudate nucleus and right and left putamen. A significant main effect of stress was observed in both the right, $F(1, 14) = 12.67$, $p < .01$, $\eta_p^2 = 0.475$, and

left caudate, $F(1, 14) = 5.00$, $p < .05$, $\eta_p^2 = 0.263$. In both cases, BOLD activity was significantly reduced under acute stress. In addition, a significant stress condition x strategy choice 2-way interaction was observed in both the right, $F(1, 14) = 7.71$, $p < .05$, $\eta_p^2 = 0.355$, and left, $F(1, 14) = 5.22$, $p < .05$, $\eta_p^2 = 0.272$, putamen (see Figures 4.3 and 4.4 respectively). Both regions exhibited a pattern of activity such that parameter estimates for conservative trials did not significantly differ between the stress and no stress conditions, yet a great increase in BOLD activity occurred for risky trials under no stress – and a large decrease for risky trials under acute stress.

During the feedback periods of the task, a notable pattern of BOLD activity emerged in these striatal regions. A significant main effect of domain in the right caudate results in significantly higher activity on gain domain trials, $F(1, 5) = 33.86$, $p < .01$, $\eta_p^2 = 0.871$. A significant stress condition x decision domain 2-way interaction was identified in the left caudate, $F(1, 5) = 5.74$, $p < .05$, $\eta_p^2 = 0.451$ (see Figure 4.5). Participants under no stress exhibited high levels left caudate BOLD activation for gain domain trials, and near zero levels for trials in the loss domain. Under the influence of acute stress, however, gain domain activation decreased and loss domain activation increased almost to the point of converging. Also during feedback, BOLD activity in the right putamen was significantly higher for gain domain trials as compared to loss, $F(1, 7) = 6.24$, $p < .05$, $\eta_p^2 = 0.471$. Finally, no significant effects were observed in the left putamen during feedback.

Cortical Regions of Interest: ACC, OFC and VLPFC

A number of cortical ROIs achieved significance as a result of the aforementioned contrast. No significant effect was observed during the stimulus/response period in the

right or left ACC. While in the loss domain right ACC exhibited BOLD activation increases for conservative trials under no stress as compared to acute stress, activation during trials where a risky choice was made was increased under stress and decreased under no stress to the point of overlapping. The reverse pattern was observed in the gain domain. No significant changes were observed in the left or right OFC, or the left VLPFC, during the stimulus/response period. During the feedback period, a main effect of decision domain involved significantly more BOLD activity on gain domain trials in both the left, $F(1, 7) = 15.50$, $p < .01$, $\eta_p^2 = 0.689$, and right ACC, $F(1, 7) = 15.87$, $p < .01$, $\eta_p^2 = 0.694$. In addition, participants BOLD activation was significantly lower under acute stress in the right ACC compared to no stress control, $F(1, 7) = 6.44$, $p < .04$, $\eta_p^2 = 0.479$. No significant effects were observed in left or right OFC, or ventrolateral PFC.

Parietal Regions of Interest: Postcentral Gyrus and Paracentral Lobule

Although the parietal ROIs were originally included as control regions, they yielded a specific pattern of results. With respect to the stimulus/response period, a stress condition by decision domain by strategy choice 3-way interaction was observed in postcentral gyrus, $F(1, 14) = 5.35$, $p < .05$, $\eta_p^2 = 0.276$. In the loss domain, participants exhibited greater BOLD activation for both risky and conservative strategy choices. This held true for conservative choices on gain domain trials, but while under stress participants exhibited a decrease in activation on risky grain domain trials while showing increased risky trial activation under no stress – essentially converging at the same midpoint in both conditions. In the paracentral lobule, a main effect of strategy choice manifested in that participants exhibited significantly greater BOLD activity for risky strategy choices, $F(1, 14) = 4.73$, $p < .05$, $\eta_p^2 = 0.252$. Turning to the feedback period

parameter estimates, no significant effect was observed in the precentral gyrus. In the paracentral lobule, however, a main effect of decision domain was observed such that participants exhibited greater activation for gain domain trials, $F(1, 7) = 7.05$, $p < .05$, $\eta_p^2 = 0.502$.

Exploratory Region of Interest: Amygdala

Definition of this ROI resulted from a 2 (stress condition: no stress vs. acute stress) x 2 (decision domain condition: loss vs. gain) x 2 (strategy choice: risky vs. conservative) analysis of covariance performed on data from the stimulus/response portions of task trials. One region in the right amygdala was observed to be significantly activated. A significant main effect of acute stress was observed here, such that BOLD activation increased under stress, $F(1, 14) = 5.81$, $p < .05$, $\eta_p^2 = 0.293$. Notably, this is the only region thus far whose BOLD activity increased resulting from a main effect of acute stress. No significant BOLD changes were observed in this region during the feedback period.

Correlations between Task-related BOLD Activity and Behavior

A number of correlations between BOLD activity in various ROIs and the behavioral data and measures were observed. In the right amygdala, parameter estimates originating in the stimulus/response period on trials where participants made risky choices under stress negatively correlated with risky choice behavior under stress, $r(21) = -0.42$, $p < .05$. Similarly, BOLD activity in the right caudate under no stress during stimulus/response on trials where participants made risky choices in the loss domain correlated negatively with risky choice behavior in the loss domain under no stress $r(21) = -0.51$, $p < .05$. Additionally, both ACC ROIs correlated with the behavioral inhibition

measure of the BIS scale. Left ACC when participants under stress received feedback of an actual loss after making a risky choice, $r(21) = -0.43$, $p < .05$, and right ACC when participants under stress happened to choose conservatively in the stimulus/response period, $r(21) = -.50$, $p < .05$. These interactions between neural activity and behavior will be further discussed below.

4.11 Discussion

In the current experiment participants engaged in a financial decision-making task while undergoing fMRI scanning, under conditions of acute stress or no stress. Measures of skin conductance, as well as salivary cortisol, were acquired. Based in part on the series of experiments presented in Chapter 2, this experiment was designed to test the nature of stress and decision-making interactions at the neural level. Specifically, it has been proposed that acute stress exposure facilitates the use of automatized forms of reasoning and decision-making. A mechanism of this type would promote the maintenance of organized and goal-oriented behavior while prefrontal-based deliberative reasoning has been compromised because of exposure to medium or extreme levels of acute stress. In addition, it was proposed that this modulatory effect might be measured by stress-related changes in BOLD activity in a combination of three central regions of interest. First, the subcortical striatal structures which form the basis of the brain's reward-processing circuitry. Second, prefrontal regions critical to deliberative thought and reasoning that are also known to be sensitive to the influence of stress. Third, the amygdala – a region known to be involved in decision making, automatized processes, and stress.

The results of this experiment only partially replicate those discussed in Chapter 2. Although measures of skin conductance taken in Experiment 5 did not indicate that participants were sufficiently stressed, it is possible that interference from the MRI contributed to this discrepancy. Nonetheless, post-experimental and salivary cortisol measures did confirm that participants had been exposed to a level of acute stress similar to the earlier line of experiments – at a sufficient level to modulate decision-making. A more central concern is that acute stress did not modulate decision-making as in Experiment 1. That is, rather than exaggerating the reflection effect present in participants' strategy choices in this experiment acute stress resulted in an increase in risky behavior overall. While may call into question the specific nature of stress-related modulation of decision-making, these data do indicate that risk-taking behavior was modulated by acute stress exposure.

Turning towards the hypotheses tested in this experiment, acute stress exposure did influence striatal activity. This effect manifested as a general decrease in caudate BOLD activity bilaterally. While some research indicates that the caudate responds to the magnitude (or quantity) of a given reward (Delgado, Locke, Stenger, & Fiez, 2003), other research has observed the caudate to be highly context dependent (Nieuwenhuis et al., 2005). Perhaps, in the case of exposure to acute stress, both standpoints are valid – as evidenced by research stating that motivation is a key factor modulating the activity of this region (Delgado et al., 2004). It may be that acute stress reduced the motivation of participants in this experiment, lessening the caudate response to reward-related information. This interpretation may find further support from research which has

observed that caudate activity is action-contingent, and that even the perception of a lack of control can reduce BOLD activity in this brain region (Tricomi et al., 2004).

Thus, acute stress could further modulate caudate activity by diminishing participants' expectancy that their actions will lead to a desirable outcome. The feedback period of the task yields a different picture entirely. While the right caudate exhibited a typical pattern of increased activity in response to perceived gains, the left caudate did not. Rather, under acute stress the expected pattern of increased BOLD activity in response to gains was greatly lessened – converging with activation in response to losses. Based on these findings it appears that the caudate is a prime candidate as a region highly sensitive to the effects of acute stress. Negative correlations between caudate activity and stress-modulated increased in risky behavior further support this view. It is also noteworthy that the putamen's response to risky choices made under stress during the stimulus/response period was also attenuated. Research indicates that the putamen plays an important role in evaluating actions based on sensory context and rewards (Haruno & Kawato, 2006), thus modulation of putamen activity in this way might explain the increases in risky behavior overall in the current experiment.

The effect of acute stress on cortical decision-making regions is more difficult to interpret. During the stimulus/response period, the right ACC did exhibit a pattern of BOLD activity that appeared to be influenced by acute stress – although this merely manifested as a marginal effect. Other cortical regions, including left ACC, both OFC ROIs and VLPFC showed no significant changes in activation of any kind. While both ACC ROIs appeared to respond to reward-containing feedback on gain domain trails,

significantly less activity was observed in both regions under acute stress. This may indicate that stress does, in fact, interfere with the typical functioning of those regions.

A primary region of interest, based on the hypotheses presented in this chapter, was the amygdala. Unfortunately, it was difficult find task-related changes in BOLD activity here – perhaps in part because of this region's small size, and the fact that stress was administered prior to the task itself. When said task-related activity was elucidated, however, it did conform to the states hypothesis of increased BOLD activity under acute stress. It is interesting to note the amygdala is the sole region to exhibit activity increases as a main effect of acute stress in this experiment. Other research has identified this region as playing a role in the behavioral biases associated with the framing effect (e.g., De Martino et al., 2006). Despite repeated attempts to elucidate framing-related activity in this region in the current experiment, this result was not observed.

Although this experiment did not fully conform to the hypotheses put forward earlier in this chapter, a number of stress-related changes in BOLD activity in subcortical regions related to reward processing were observed. Certain cortical ROIs, such as the ACC, also exhibited stress related alterations in activity. Furthermore acute stress did modulate risk-taking in this paradigm, although not as predicted. It is clear that stress-related modulation of decision-making is a highly complex phenomenon, subject to large individual differences. High inter-subject variability in risk-preferences as well as stress reactivity may, however, be overcome. Despite the difficulties presented by such factors, this experiment demonstrated that the exposure to acute stress can modulate the activity of diverse brain regions, both cortical and subcortical, as well as behavior. While the

exact nature of this modulation is unclear, as yet, this experiment yielded results that will be highly useful in future inquires on this topic.

Chapter 5

General Discussion

The goal of this dissertation was to examine the influence of acute stress on decision-making at the behavioral and neural levels, utilizing two different financial decision-making paradigms. Taking a dual-process stance, it was hypothesized that acutely stressed participants would come to rely more heavily on automatized (or system 1) processing while deliberative (or system 2) faculties were compromised. This hypothesis originated in the proposal that falling back on automatized processing would enable a decision-maker to maintain organized and goal-directed behavior under the disruptive influence of stress. Using Prospect Theory as a platform, it was proposed that the reflection effect – a robust phenomenon by which individuals make more risky choices when a decision is phrased as a possible loss but more conservative ones when a decision is phrased as a possible gain – constituted an automatized process that could be used to test this dual-process theory in the laboratory setting.

In Experiments 1 through 3 participants engaged in a financial decision-making task where they were asked to make binary choices that were deemed risky or conservative in the loss and gain domains separately. The results of Experiment 1 indicated that exposure to acute stress modulated risk-taking decision-making behaviors. Specifically, it was observed that under acute stress participants' risk-taking was modulated through an exaggeration of Prospect Theory's reflection effect. Experiments 2 and 3 were designed to address concerns of a practice effect confounding the findings of Experiment 1. In both experiments, results supported the hypothesis that acute stress did in fact modulate decision-making in Experiment 1 by exaggerating the reflection effect.

Experiment 4 was designed to more directly test a central component of the theory presented in this dissertations – namely, that acute stress of sufficient intensity causes a shift from controlled or deliberative (system 2) to automatized (system 1) processing. In order to accomplish this, Experiment 4 examined the impact of acute stress on decisions influenced by preferences acquired via instrumental conditioning. It was hypothesized that acute stress would result in an increased reliance on previously learned (overtrained) preferences even after the values of the stimuli were altered, and also that acute stress would in fact facilitate conditioning. Participants who were exposed to acute stress did choose the stimulus previously associated with the highest reward value significantly more often than did non-stressed participants – even though the value of the stimulus at that point in the design had been reduced to zero. In addition, a marginally significant effect was observed such that participants who were under acute stress made better choices than participants who were not. Taken together, these results indicate that acute stress effects do generalize to other types of decision-making – but that these effects are largely dependent upon task demands. In support of the hypothesis that acute stress causes a shift from deliberative to automatized processing, instrumental conditioning of preferences (and use of those preferences) was enhanced by acute stress in this paradigm.

Finally in Experiment 5, a design similar to the one used in Experiments 1, 2 and 3 was employed while participants underwent fMRI scanning. It was hypothesized that participants would exhibit a similar exaggeration of the reflection effect in their decision-making under acute stress. It was further hypothesized that fMRI acquired BOLD activity would be significantly decreased under acute stress in cortical prefrontal regions

associated with deliberative reasoning, and significantly increased in subcortical regions associated with automatized processing such as the amygdala. Finally, it was proposed that the striatum – given their role in reward processing and decision-making – might serve as a locus for the modulatory effect of acute stress on decision-making, although this hypothesis was nondirectional. A different pattern of behavior was observed in Experiment 5, in that participants under acute stress made more risky choices overall. This is consistent with an increase in reflection in the loss domain, but not in the gain domain. In accordance with the stated hypotheses significantly less BOLD activity was observed in cortical prefrontal regions, and activity was significantly greater in the amygdala, under acute stress. Furthermore, striatal responses to rewards and punishments were modulated – such that the caudate's typical response was attenuated in the loss domain under acute stress, as was the putamen's response to risky choice behavior. Although these results are only partially consistent with those obtained in Experiment 1, they do support the original hypothesis of modulation of decision-making by acute stress at both the behavioral and neural levels.

The notable behavioral differences between Experiments 1 and 5 certainly merit further exploration. Multiple factors might account for this inconsistency. For example, the MRI itself is a loud environment which could have distracted the participants. In addition, due to the particular even-related design used in Experiment 5 the experiment itself was considerable longer than Experiment 1. Furthermore, more gambles were presented to the participants in Experiment 5 (six in each domain) than Experiment 1 (2 in each domain). It is possible that this increase in memory load further complicated that

pattern of result that emerged. Individual differences in risk-preferences and reactions to rewards and punishments may also account for differences in performance.

In Experiment 1, higher behavioral inhibition scores (BIS) were associated with increased risky choice behavior in the loss domain but the opposite in the gain domain. Participants higher in BIS should be more inhibited from pursuing goals that might lead to aversive outcomes (i.e., punishments). Thus, the pattern of behavior just mentioned is highly plausible. High BIS participants avoided pursuit of an option likely to result in an aversive outcome (i.e., a loss of money) by choosing the risky option in the loss domain – associated with only a small chance of that loss actually coming to pass. Conversely, high BIS participants avoided pursuit of goals likely to result in an aversive outcome in the gain domain (i.e., a reward of zero dollars) by choosing the conservative option – which offered an increased chance of an actual reward while reducing that reward's magnitude. Low BIS participants exhibited no such inclination. Although BIS covaried with stress condition and decision domain to a marginally significant degree in Experiment 5, a multiple moderated regression uncovered no significant interaction, perhaps due to a lack of sufficient power. Nonetheless it is clear that individual difference measures offer vital insights into the nature of stress and decision-making interactions, and as such they will be rigorously incorporated into future designs.

An additional factor that must be taken into consideration involved the context of the stress manipulation itself in Experiment 1 as compared to Experiment 5. Because Experiment 1 involved a traditional cold pressor task, where participants were asked to insert their hand into a bowl of ice-cold water but were free to remove their hand at any time, the acute stress manipulation could have been perceived as controllable by the

participants. In contrast, participants in Experiment 5 were exposed to cold stress via an arm wrap that met the requirements of performing such a task in the MRI environment. Because these participants would have needed to ask to be removed from the MRI to end the acute stress procedure prematurely, and none did, participants might have perceived the manner of stress used in this experiment as being uncontrollable. Research indicates that perceived self-inefficacy in response to stress (as in the case of Experiment 5) can modulate the physiological to stress itself (Bandura, Cioffi, Barr Taylor, & Brouillard, 1988). Thus, the stressor utilized in Experiments 1 and 5 might have different in this regard. Future research will focus on teasing apart the contributions of these subtle factors to the modulation of decision-making by acute stress.

Despite these differences in behavioral performance, based on the results of these studies it is evident that acute stress is capable of modulating decision-making at both the behavioral and neural levels. While the nature of this modulation is highly complex and will require a great deal of research to elucidate, this dissertation has taken the necessary first steps in that direction. Many topics that were discussed in this dissertation require further examination. For example, what might form the neural basis of a shift between deliberative and automatic processing under acute stress? One standpoint would suggest that this shift should be accompanied by a shift in the locus of neural activity from frontal to subcortical and parietal brain regions, based on the regions proposed to be involved in those respective processes (e.g., Schneider & Chein, 2003). Given the pattern of activity observed in these brain regions in Experiment 5, this explanation is a plausible one. Much work remains to be done, however, in elucidating exactly which brain regions are involved in deliberative versus automatized processes in tasks of the types presented in

this dissertation (e.g., Satpute & Lieberman, 2006). Furthermore, some regions may be sensitive to the effects of acute stress while others may not – or sensitive to some types of stress and not others. All of these topics are important goals for future research.

The goal of this dissertation was to take the first step towards gaining an understanding of the interaction between acute stress and financial decision-making. The results imply that people experiencing acute stress, of sufficient intensity to disrupt deliberative reasoning, undergo a shift towards more automatized types of reasoning and behaviors to maintain goal-directed behavior. Importantly, day-to-day decision-making unavoidably occurs in situations subject to various forms of stress. While some research on decision-making under stress in the context of military and firefighting personnel supports the idea such a shift is essential for individuals to be able continue to make informed and goal-oriented decisions (e.g., Orasanu & Backer, 1996; Sinha, 2005), the nature of this shift remains unclear.

Furthermore, the implications of this theory are far-ranging – reaching from the financiers managing the economy to the individuals that comprise it. For example, an investment banker whose automatized reactions to risk promote increased in risk-taking might become dangerously risky under stress. Conversely, a person who is risk-averse might make poor financial decisions under stress by acting in an overly conservative manner – removing valuable investments from the market prematurely due to the psychological stress engendered by terrifying headlines and a dwindling savings account. If anything, the unstable climate currently facing the world economy drives home the importance of developing a better understanding this highly complex relationship.

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Figure 2.1. An illustration of the financial decision-making task design used in Experiments 1 through 3.

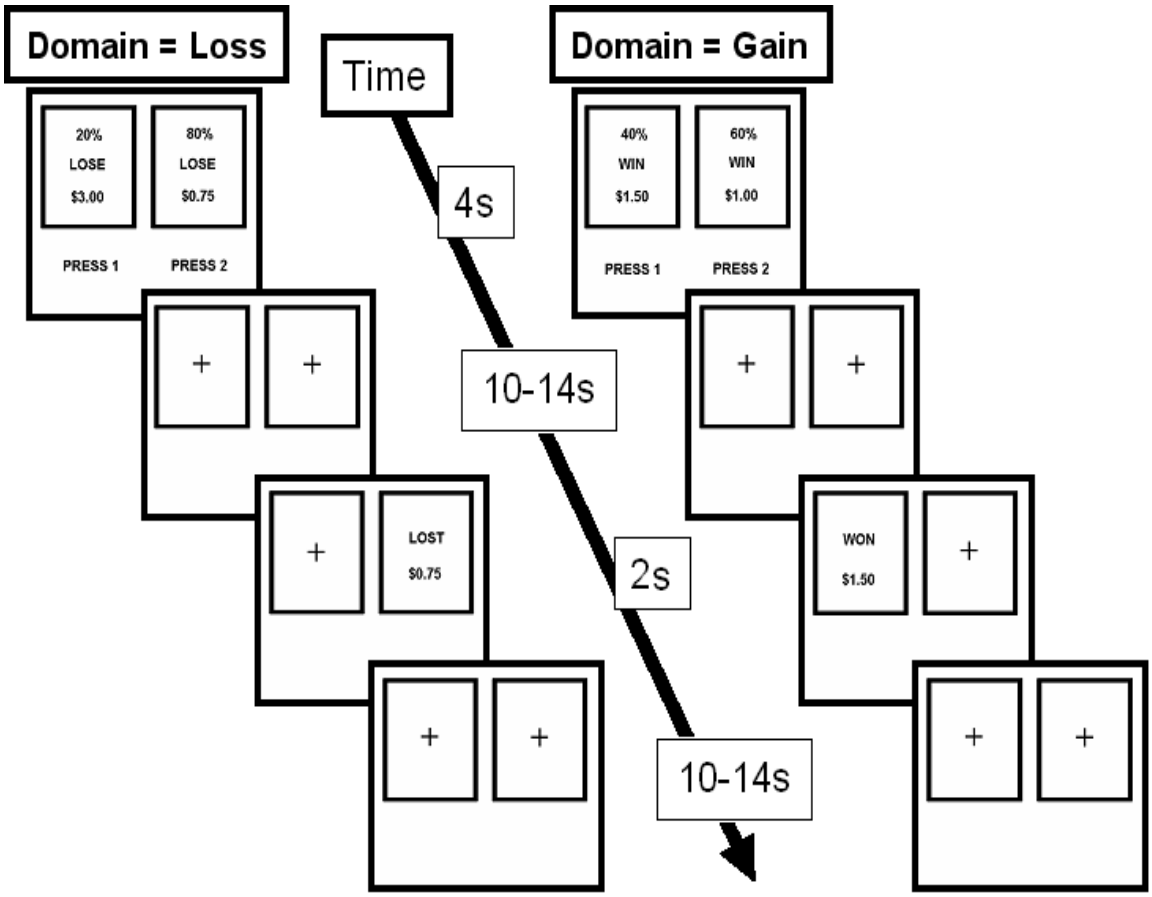


Figure 2.2. Average galvanic skin response level in under acute stress or no-stress control (in microsiemens).

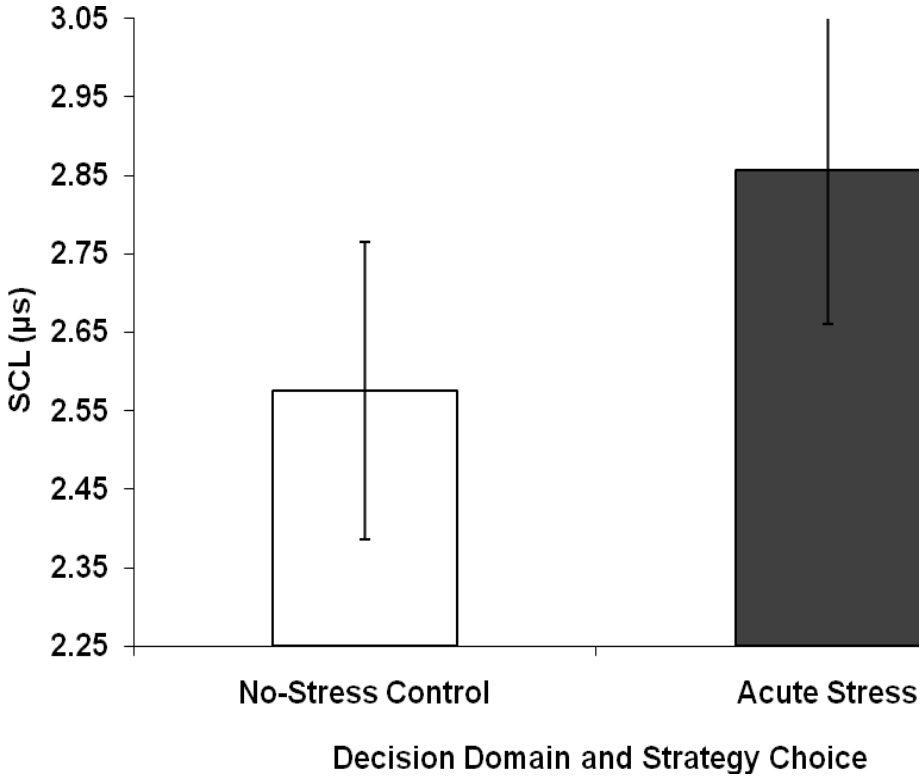


Figure 2.3. Strategy choice data for Experiment 1 (analyses performed on risky choices only, conservative choices added for completeness).

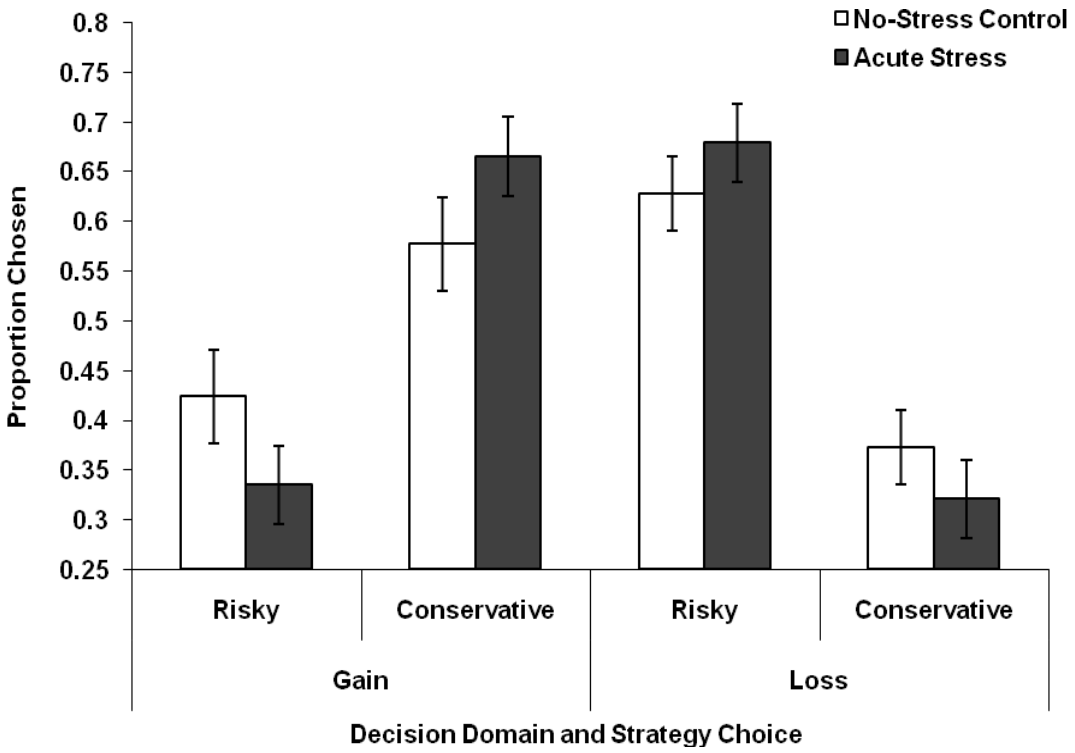


Figure 2.4. Analysis of simple slopes from BIS covariate multiple moderated regressions. NOTE: Low BIS = 1 SD below BIS mean, moderate BIS = BIS mean, high BIS = 1 SD above the mean.

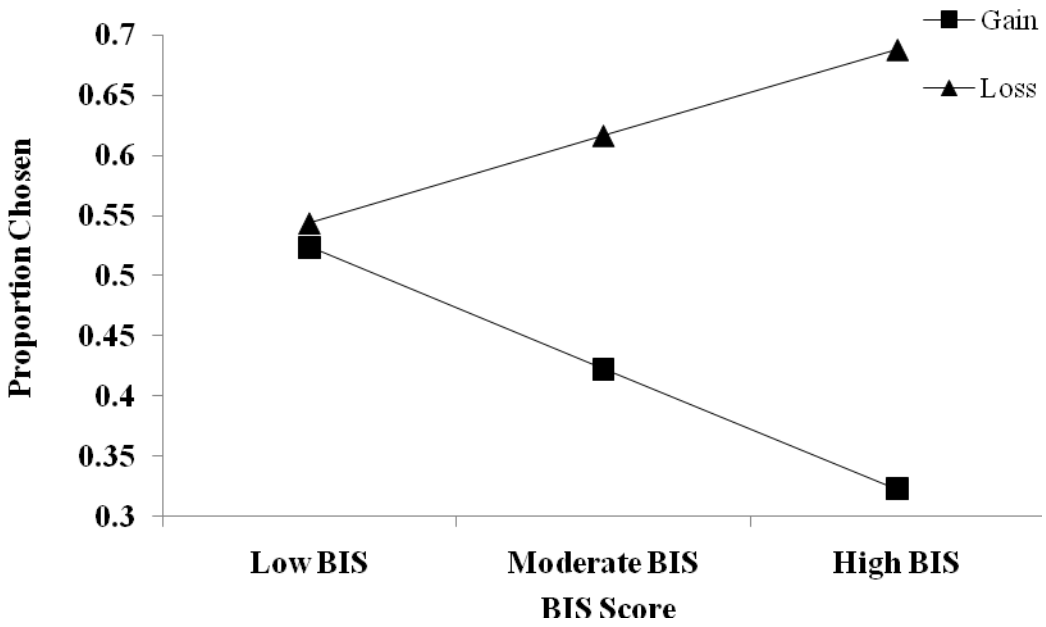


Figure 2.5. Strategy choice data from Experiment 1 (no stress blocks) and Experiment 2 (acute stress blocks) participants, yoked by skin conductance levels

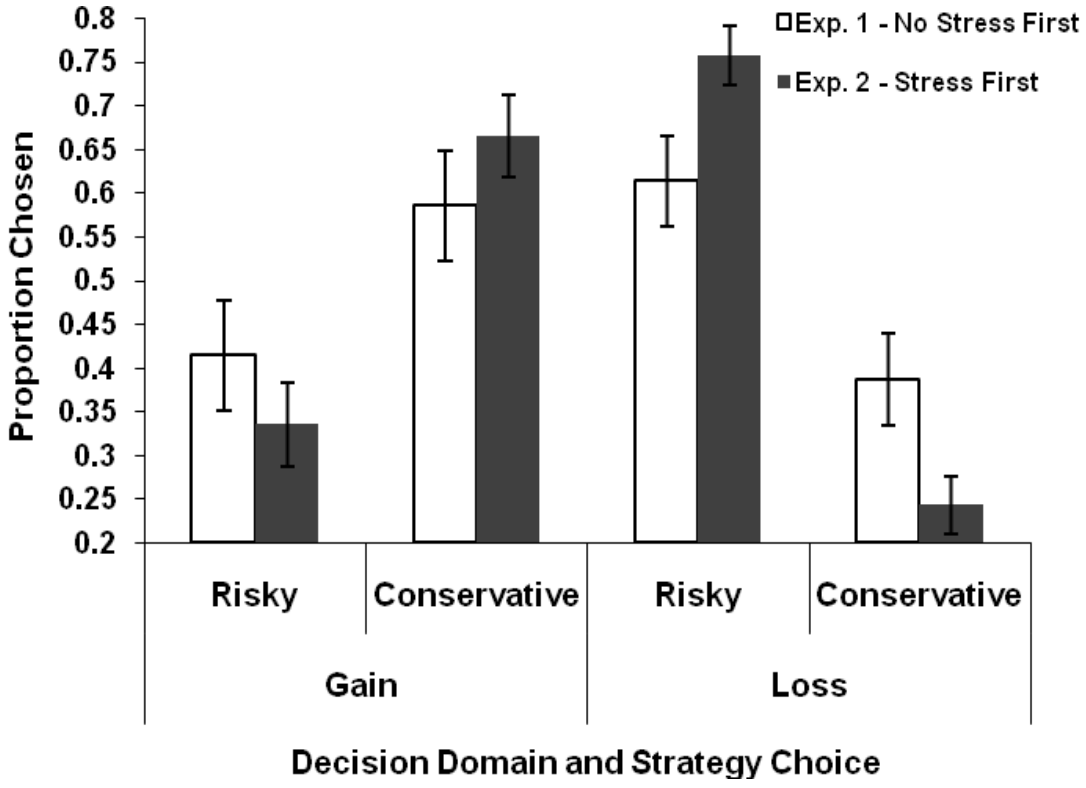


Figure 2.6. Strategy choce data for Experiment 3 participants (no stress control only).

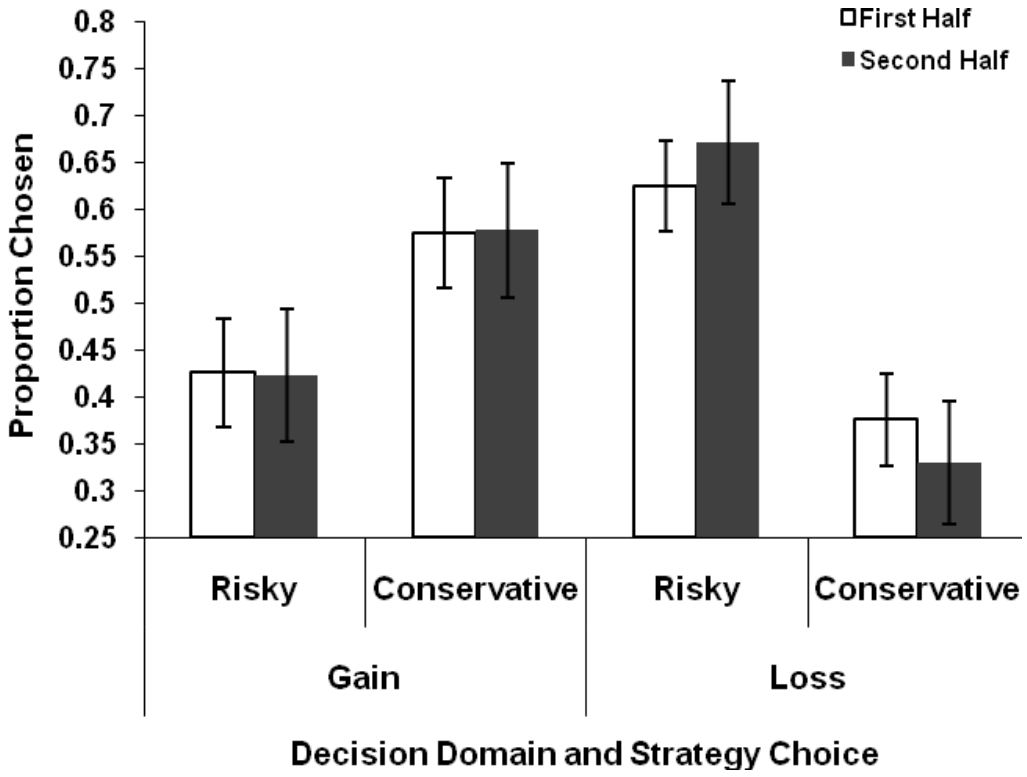


Figure 3.1. An illustration of the design of Experiment 4.

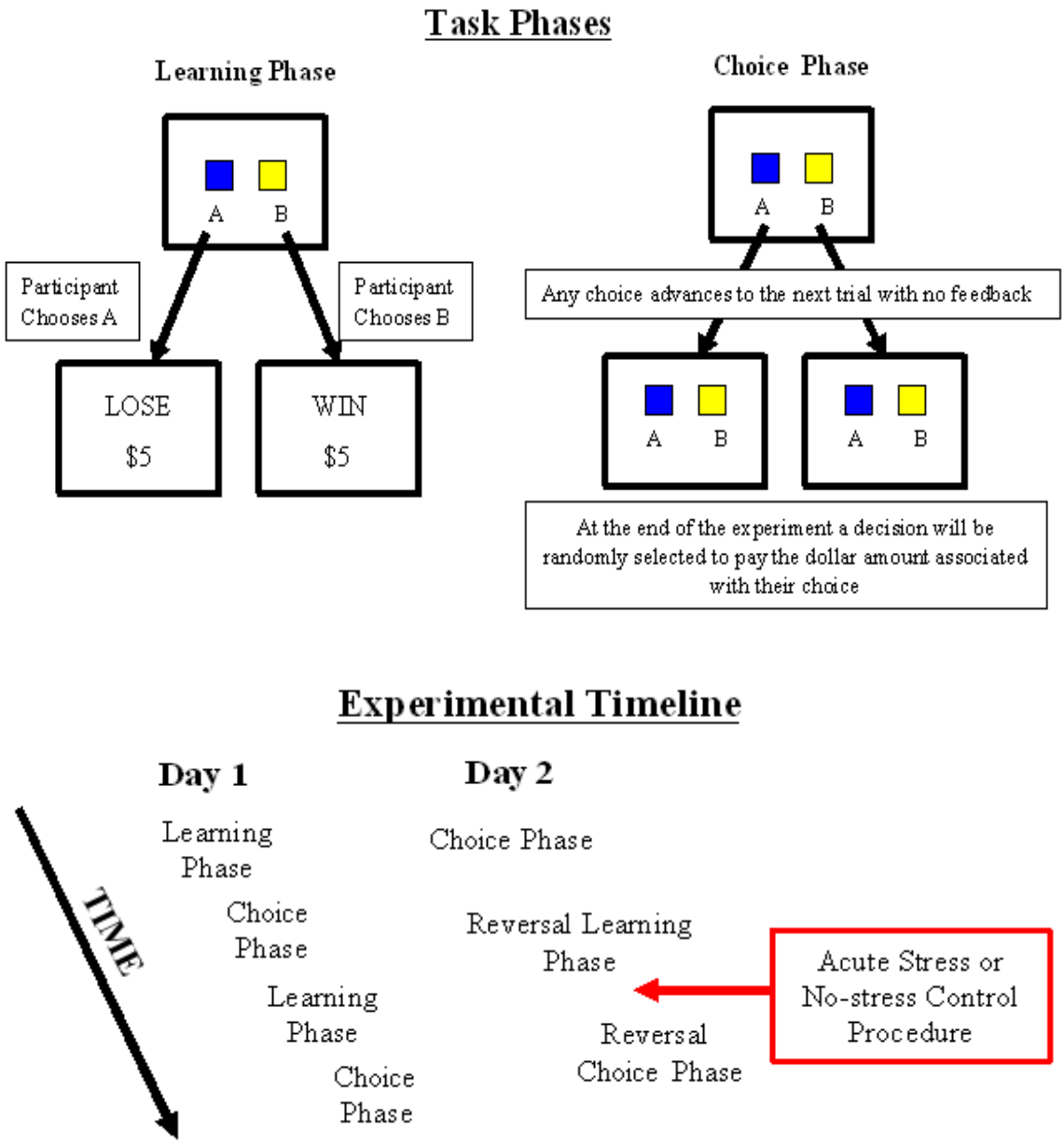


Figure 3.2. Choice data from Experiment 4, showing an increase in good choices and decrease in bad by block 3 at the beginning of day 2.

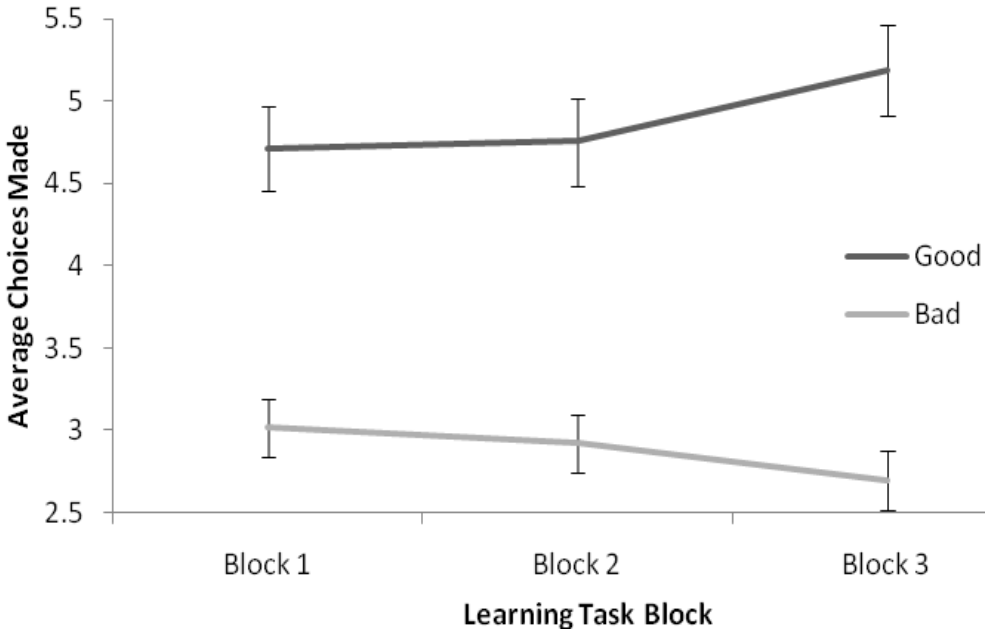


Figure 3.3. Experiment 4 choice data showing that subjects were sensitive to expected utility in their decision-making.

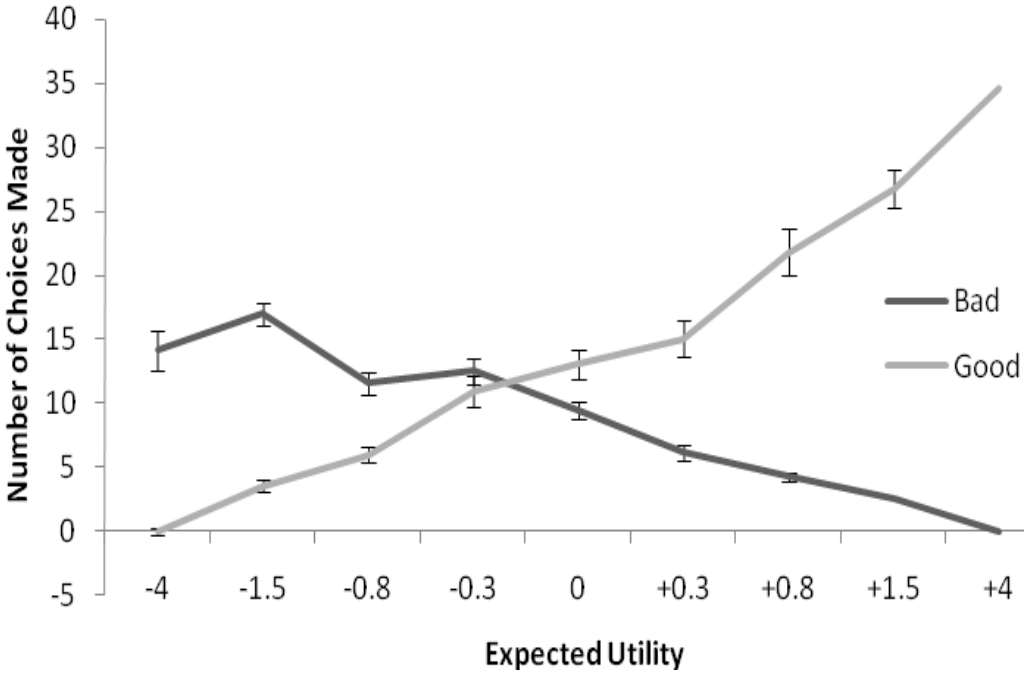


Figure 4.1. Anatomy of the OMPFC, reproduced from (Ongur & Price, 2000).

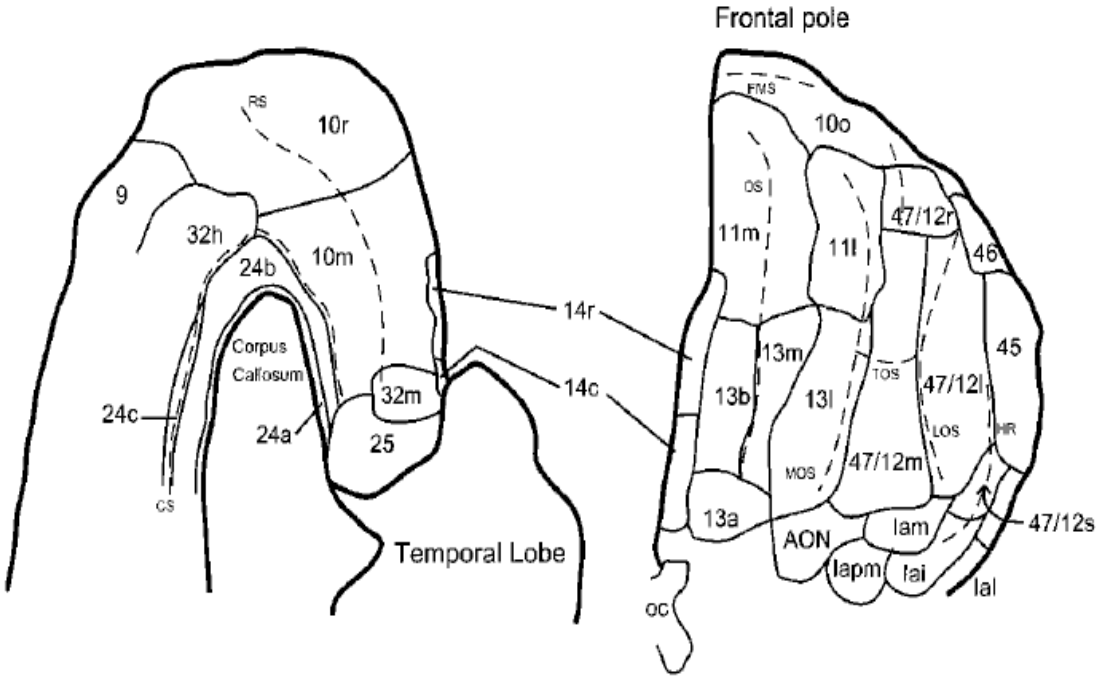


Figure 4.2. Experiment 5 behavioral strategy choice data (analyses performed on risky choices only, conservative choices added for completeness).

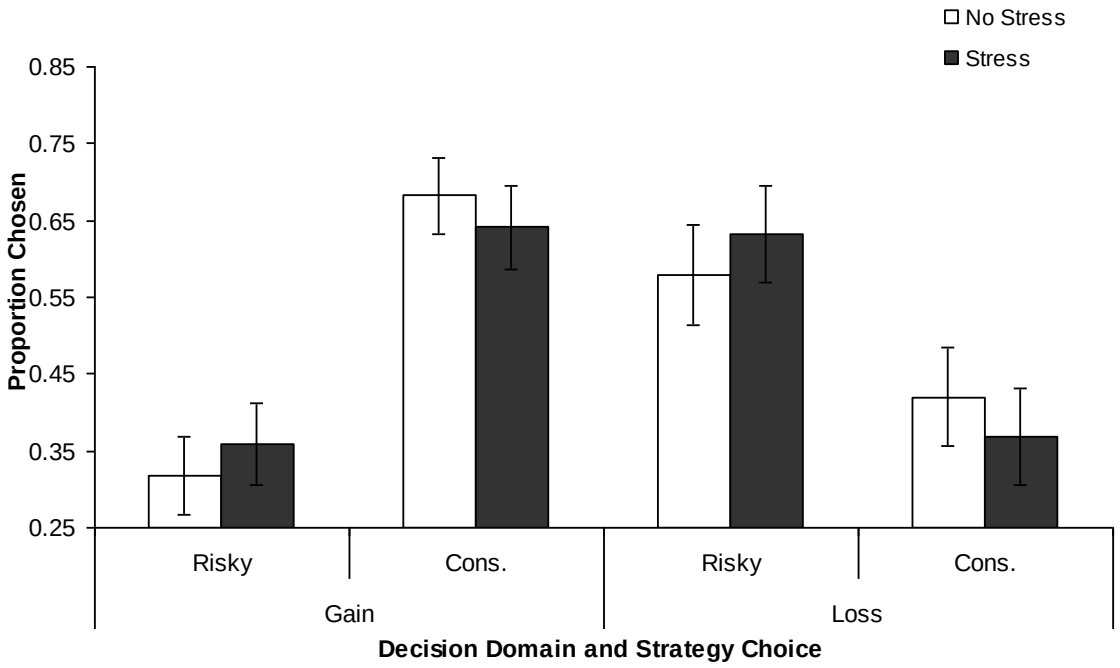
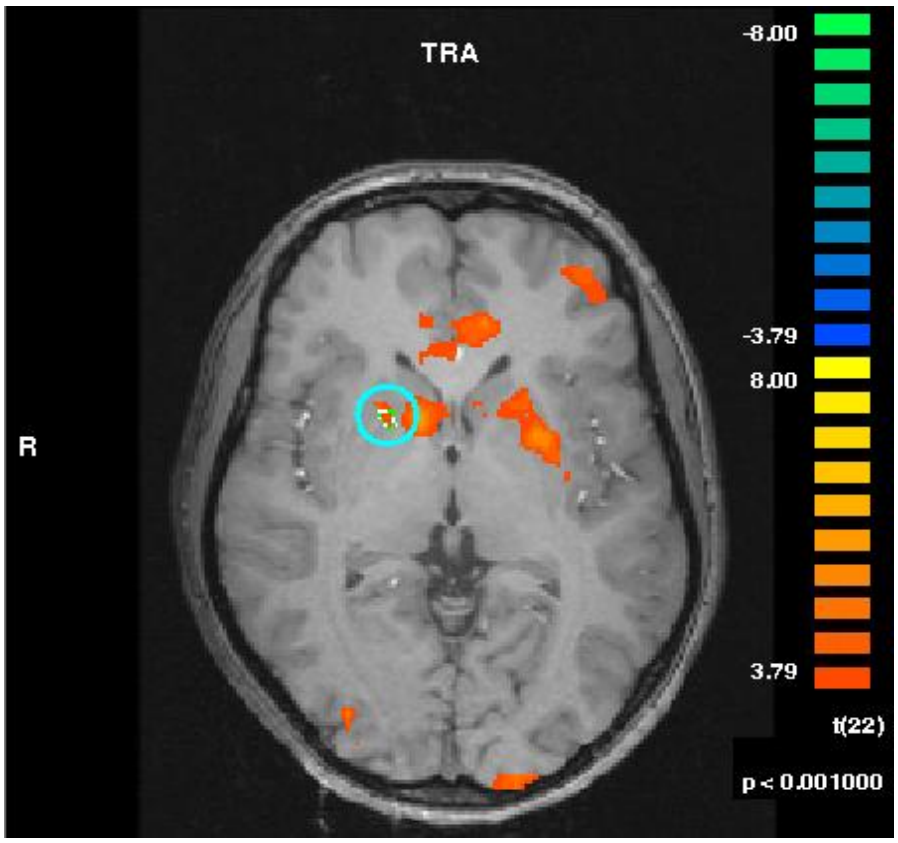


Figure 4.3. Right Putamen: Significant stress condition x strategy choice interaction (Stimulus/Response period).



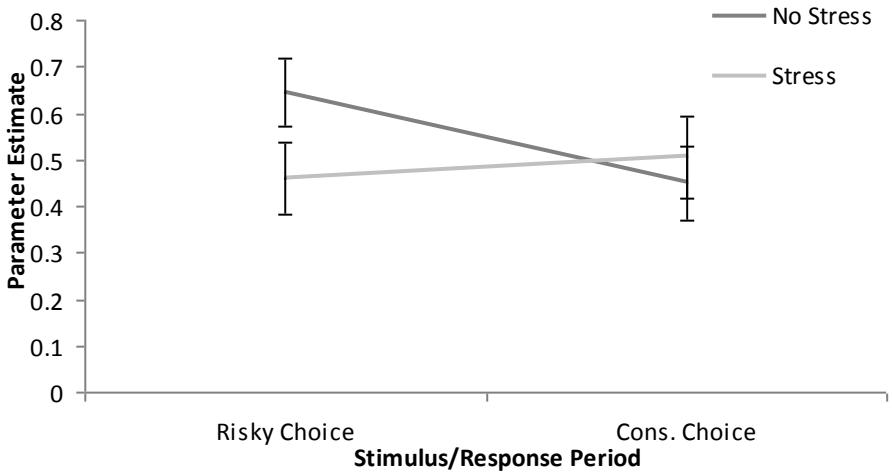


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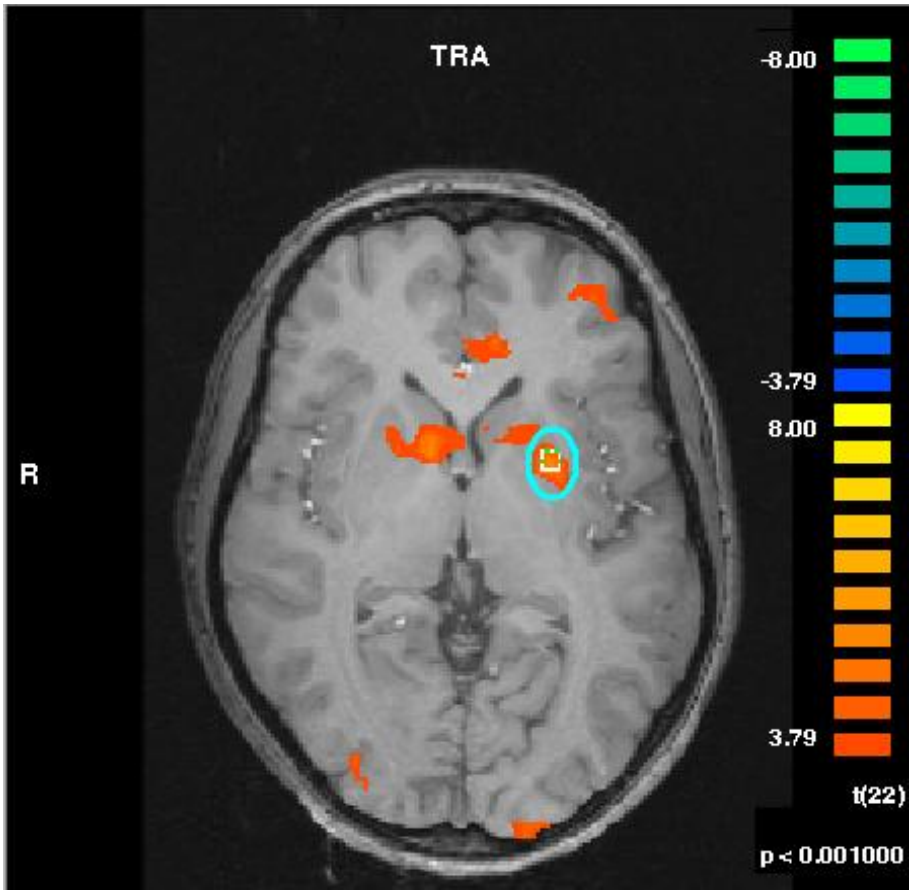
Figure 4.4. Left Putamen: Significant stress condition x strategy choice interaction (Stimulus/Response period).



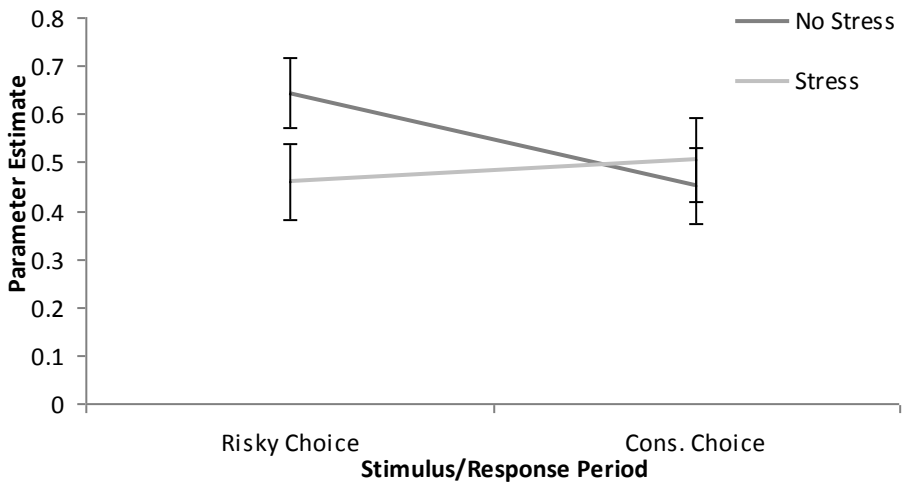
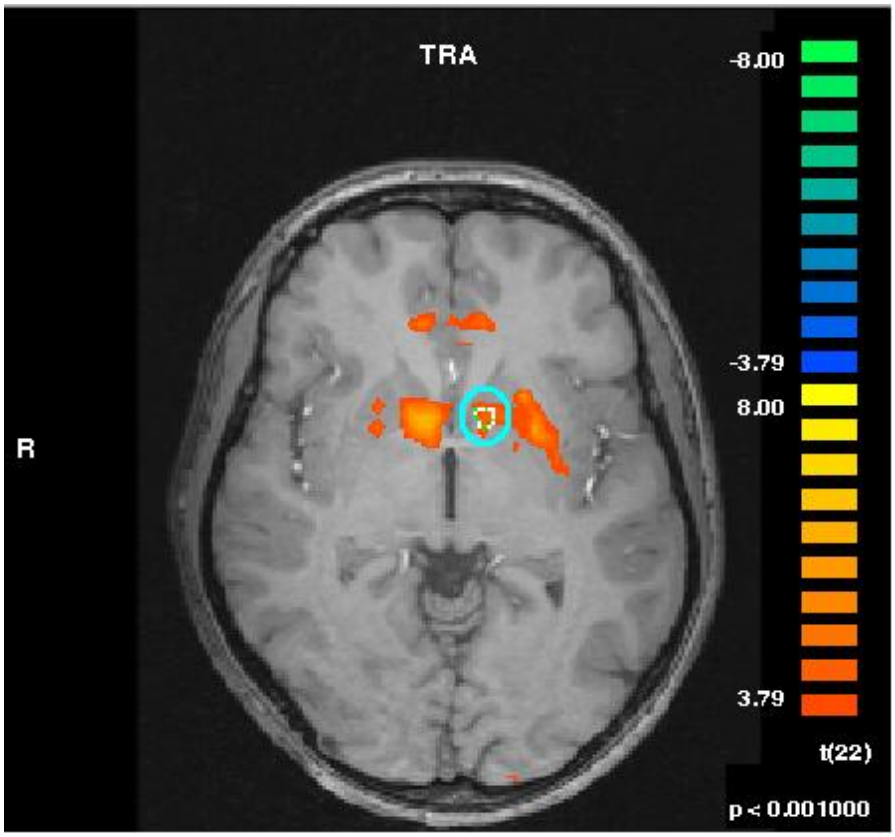


Figure 4.5. Left Caudate: Significant stress condition x decision domain 2-way interaction (Feedback period).



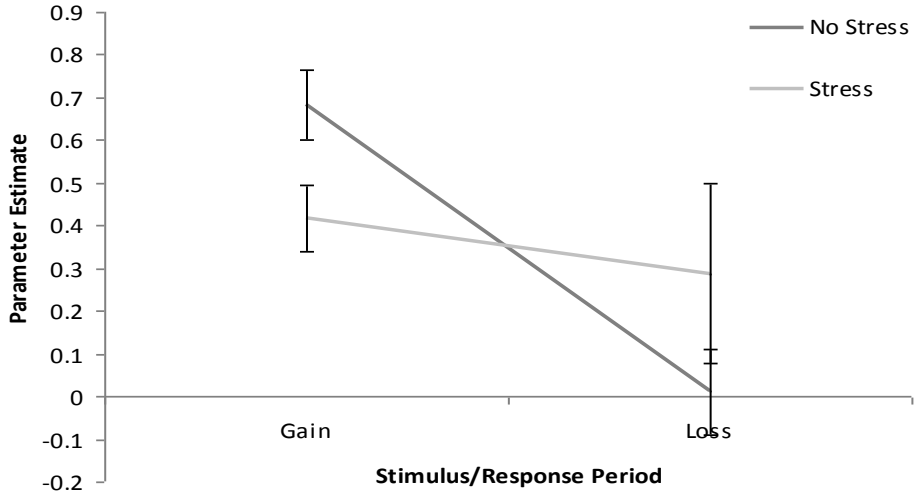


Table 2.1. Summary of the moderated multiple regression performed on in Experiment 1, regressing the proportion of risky strategy choices onto stress condition and BIS.

Gain Domain Variable	B	SE B	β	*p*
Step 1 $R^2 = 0.256$ ($p < .01$)				
Stress condition	-0.097	0.053	-0.221	> .05
BIS	-0.032	0.009	-0.455	< .05
Step 2 $\Delta R^2 = 0.007$				
Stress condition	0.126	0.335	0.288	> .05
BIS	-0.027	0.012	-0.373	< .05
Stress condition x BIS	-0.012	0.017	-0.522	> .05

Loss Domain Variable	B	SE B	β	*p*
Step 1 $R^2 = 0.153$ ($p < .01$)				
Stress condition	0.051	0.050	0.131	> .05
BIS	0.023	0.008	0.368	< .05
Step 2 $\Delta R^2 = 0.002$				
Stress condition	0.166	0.317	0.428	> .05
BIS	0.026	0.012	0.416	< .05
Stress condition x BIS	-0.006	0.016	-0.304	> .05

Table 2.2. Experiment 1 correlation matrix (N = 27).

	1	2	3	4	5	6	7	8	9
1. No Stress Gain Risky Choices	-								
2. No Stress Loss Risky Choices	-0.51	-							
3. Stress Gain Risky Choices	0.60	-0.52	-						
4. Stress Loss Risky Choices	-0.16	0.62	**-0.44**	-					
5. No Stress WM Task Accuracy	-0.18	0.03	0.08	-0.15	-				
6. Stress WM Task Accuracy	0.03	0.24	-0.30	0.33	0.16	-			
7. Subjective Stress Ratings	0.11	-0.08	-0.08	0.17	-0.26	0.22	-		
8. No Stress SCL	-0.05	0.32	0.08	0.13	0.04	0.19	-0.19	-	
9. Stress SCL	-0.16	0.29	0.07	0.10	0.01	0.09	-0.15	0.97	-

Bold, $p < .05$; Underlined, $p < .01$

Table 2.3. Experiment 2 correlation matrix (N = 27).

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1. No Stress Gain Risky Choices	-								
2. No Stress Loss Risky Choices	-0.14	-							
3. Stress Gain Risky Choices	0.34	-0.12	-						
4. Stress Loss Risky Choices	-0.09	0.37	-0.53	-					
5. No Stress WM Task Accuracy	-0.29	-0.03	0.06	-0.12	-				
6. Stress WM Task Accuracy	0.36	0.10	0.04	0.04	-0.20	-			
7. Subjective Stress Ratings	0.44	-0.13	-0.07	0.03	-0.23	0.43	-		
8. No Stress SCL	0.10	-0.06	-0.19	0.19	-0.32	0.12	0.16	-	
9. Stress SCL	0.14	0.12	-0.24	0.39	-0.09	0.35	0.26	0.68	-

Bold, $p < .05$; Underlined, $p < .01$

Table 2.4. Experiment 3 correlation matrix (N = 21).

	1	**2**	**3**	**4**	**5**	**6**	**7**
1. No Stress Gain Risky Choices	-						
2. No Stress Loss Risky Choices	-0.08	-					
3. Stress Gain Risky Choices	0.93	-0.14	-				
4. Stress Loss Risky Choices	-0.01	0.88	-0.04	-			
5. No Stress WM Task Accuracy	0.20	0.23	0.22	0.24	-		
6. Stress WM Task Accuracy	0.33	0.01	0.27	-0.11	0.20	-	
7. Subjective Stress Ratings	-0.19	-0.17	-0.24	-0.02	0.04	0.11	-

Bold, $p < .05$; Underlined, $p < .01$

Table 3.1. Gamble design from Experiment 4.

Initial Choice Tasks				
Probability of:				
Win	Loss	Payoff	Utility	
90%	10%	$5	4	
65%	35%	$5	1.5	
90%	10%	$1	0.8	
65%	35%	$1	0.3	
-	-	$0	0	
35%	65%	$1	-0.3	
10%	90%	$1	-0.8	
35%	65%	$5	-1.5	
10%	90%	$5	-4	

Reversal Choice Task				
Probability of:				
Win	Loss	Payoff	Utility	
90%	10%	$5	4	
65%	35%	$5	1.5	
90%	10%	$1	0.8	
65%	35%	$1	0.3	
-	-	$0	0	
35%	65%	$1	-0.3	
10%	90%	$1	-0.8	
35%	65%	$5	-1.5	
10%	90%	$5	-4	

Table 3.2. Experiment 4 correlation matrix during the reversal choice task (N = 28).

	1	2	3	4	5	6
1. Bad Choices	-					
2. Good Choices	-0.97	-				
3. Best Pre-Reversal Square Choices	-0.37	0.36	-			
4. Subjective Stress Ratings	-0.09	0.09	0.20	-		
5. No Stress SCL	-0.04	0.09	0.17	-0.18	-	
6. Stress SCL	-0.20	0.22	0.17	-0.22	0.66	-

Bold, $p < .05$; Underlined, $p < .01$

Table 4.1. Design of the games from Experiment 5.

Risky Choice		Conservative Choice		
Probability	Contingency	Probability	Contingency	Expected Value
20%	$3.48	80%	$0.87	0.7
20%	$3.00	80%	$0.75	0.6
20%	$2.52	80%	$0.63	0.5
40%	$1.74	60%	$1.16	0.7
40%	$1.50	60%	$1.00	0.6
40%	$1.26	60%	$0.84	0.5

Table 4.2. Experiment 5 correlation matrix (N = 23).

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1. No Stress Gain Risky Choices	-									
2. No Stress Loss Risky Choices	**-0.47**	-								
3. Stress Gain Risky Choices	0.86	-0.39	-							
4. Stress Loss Risky Choices	-0.57	0.83	-0.62	-						
5. Subjective Stress Ratings	0.16	-0.19	0.16	-0.22	-					
6. Post Anatomic Cortisol Baseline	-0.18	**0.50**	-0.10	0.36	0.16	-				
7. Cortisol No Stress (Block 1)	-0.19	**0.46**	-0.11	0.32	0.08	0.96	-			
8. Cortisol Stress (Block 2)	-0.27	0.22	-0.10	0.19	0.21	0.64	0.64	-		
9. Cortisol No Stress (Block 3)	-0.26	0.15	-0.08	0.11	0.31	0.54	0.57	0.91	-	
10. Cortisol Stress (Block 4)	0.00	-0.14	0.13	-0.10	0.27	0.23	0.23	0.75	0.83	-

Bold, $p < .05$; Underlined, $p < .01$

Table 4.3. Summary of the moderated multiple regression performed on in Experiment 5, regressing the proportion of risky strategy choices onto stress condition and BIS in each domain.

Gain Domain

Variable	B	SE B	β	*p*
Step 1 $R^2 = 0.018$				
Stress condition	0.041	0.071	0.087	> .05
BIS	-0.006	0.009	-0.102	> .05
Step 2 $\Delta R^2 = 0.015$				
Stress condition	0.341	0.380	0.724	> .05
BIS	0.001	0.013	0.0203	> .05
Stress condition x BIS	-0.015	0.019	-0.660	> .05

Loss Domain

Variable	B	SE B	β	*p*
Step 1 $R^2 = 0.153$				
Stress condition	0.049	0.089	0.083	> .05
BIS	0.012	0.012	0.149	> .05
Step 2 $\Delta R^2 = 0.005$				
Stress condition	-0.174	0.479	-0.293	> .05
BIS	0.006	0.017	0.077	> .05
Stress condition x BIS	0.011	0.023	0.390	> .05

Table 4.4. Table of significant clusters from fMRI Experiment 5.

				Tailarach Coordinates		
Region of Activation	Voxels	Laterality	*p*	x	y	x
Postive - Negative Feedback						
Caudate	260	R	<.000012	8	7	0
Caudate	144	L	< .001	-9	9	1
Anterior Cingulate	128	R	< .001	7	35	0
Anterior Cingulate	166	L	< .001	-7	35	4
Putamen	114	R	< .001	19	7	5
Putamen	198	L	< .001	-25	3	5
Orbitofrontal Cortex	40	R	< .001	33	40	-1
Orbitofrontal Cortex	19	L	< .001	-30	41	-3
Parietal Lobe - Postcentral Gyrus	85	L	< .001	-29	-32	51
Parietal Lobe - Paracentral Lobule	163	L	< .001	-5	-26	52
Lateral Middle Frontal Gyrus	108	L	< .001			
Stimulus Period: Stress x Domain x Strategy ANCOVA						
Amygdala	56	R	< .01	27	3	-4

Appendix

Post-experimental surveys and questionnaires

Figure A1. BIS/BAS.

BIS-BAS Carver & White, 1994 ID:_____

For each of the following statements, please indicate **how much you agree with the statement**. Please provide a rating from **1 to 4**, using the following scale:

1	2	3	4
Strongly disagree			Strongly agree

_____ 1. If I think something unpleasant is going to happen I usually get pretty "worked up".
_____ 2. I worry about making mistakes.
_____ 3. Criticism or scolding hurts me quite a bit.
_____ 4. I feel pretty worried or upset when I think or know somebody is angry at me.
_____ 5. Even if something bad is about to happen to me, I rarely experience fear or nervousness.
_____ 6. I feel worried when I think I have done something poorly.
_____ 7. I have very few fears compared to my friends.
_____ 8. When I get something I want, I feel excited and energized.
_____ 9. When I'm doing well at something, I love to keep at it.
_____ 10. When good things happen to me, it affects me strongly.
_____ 11. It would excite me to win a contest.
_____ 12. When I see an opportunity for something I like, I get excited right away.
_____ 13. When I want something, I usually go all-out to get it.
_____ 14. I go out of my way to get things I want.
_____ 15. If I see a chance to get something I want, I move on it right away.
_____ 16. When I go after something I use a "no holds barred" approach.
_____ 17. I will often do things for no other reason than that they might be fun.
_____ 18. I crave excitement and new sensations.
_____ 19. I'm always willing to try something new if I think it will be fun.
_____ 20. I often act on the spur of the moment.

Figure A2. Penny Game.

Instructions

Your decision sheet shows ten decisions listed on the left. Each decision is a paired choice between "Option A" and "Option B." You will make ten choices and record these in the final column, but only one of them will be used in the end to determine your earnings. Before you start making your ten choices, please let us explain how these choices will affect your earnings for this part of the experiment.

We have ten small pieces of paper in a cup; each piece of paper has a number—from one to ten—written on it. After you have made all of your choices, you will then select two pieces of paper from this cup (replacing the first and shaking the cup before selecting the second of course). The first piece of paper will be used to select which of the ten decisions to use, and the second will be used to determine what your payoff will be (as according to the choice you made for that question). Even though you will make ten decisions, only one of these will end up affecting your earnings, but you will not know in advance which decision will be used. Obviously, each decision has an equal chance of being used in the end.

Now, please look at Decision 1 at the top. Option A pays 200 pennies if you draw 1, and it pays 160 pennies if your draw is 2-10. Option B yields 385 pennies if your draw is 1, and it pays 10 pennies if your draw is 2-10. The other Decisions are similar, except that as you move down the table, the chances of the higher payoff for each option increase. In fact, for Decision 10 in the bottom row, the draw will not be needed since each option pays the highest payoff for sure, so your choice here is between 200 pennies or 385 pennies.

To summarize, you will make ten choices: for each decision row you will have to choose between Option A and Option B. You may choose A for some decision rows and B for other rows, and you may change your decisions and make them in any order. When you are finished, we will give you the cup of paper pieces and you will choose two pieces of paper to determine your payoff. Your earnings (in pennies) for this choice will be added to your previous earnings, and you will be paid all earnings in cash when we finish.

Are there any questions? Now you may begin making your choices. Please print the letter of your choice (A or B) clearly in the box on the right side of the sheet.

Figure A2. Penny Game *(continued).*

ID: _____

	Option A	Option B	Your Choice A or B
Decision 1	200 if throw of die is 1 160 if throw of die is 2-10	385 if throw of die is 1 10 if throw of die is 2-10	
Decision 2	200 if throw of die is 1-2 160 if throw of die is 3-10	385 if throw of die is 1-2 10 if throw of die is 3-10	
Decision 3	200 if throw of die is 1-3 160 if throw of die is 4-10	385 if throw of die is 1-3 10 if throw of die is 4-10	
Decision 4	200 if throw of die is 1-4 160 if throw of die is 5-10	385 if throw of die is 1-4 10 if throw of die is 5-10	
Decision 5	200 if throw of die is 1-5 160 if throw of die is 6-10	385 if throw of die is 1-5 10 if throw of die is 6-10	
Decision 6	200 if throw of die is 1-6 160 if throw of die is 7-10	385 if throw of die is 1-6 10 if throw of die is 7-10	
Decision 7	200 if throw of die is 1-7 160 if throw of die is 8-10	385 if throw of die is 1-7 10 if throw of die is 8-10	
Decision 8	200 if throw of die is 1-8 160 if throw of die is 9-10	385 if throw of die is 1-8 10 if throw of die is 9-10	
Decision 9	200 if throw of die is 1-9 160 if throw of die is 10	385 if throw of die is 1-9 10 if throw of die is 10	
Decision 10	200 if throw of die is 1-10	385 if throw of die is 1-10	

Decision used: _____, Number selected: _____ Your earnings: _____

Figure A2. Penny Game *(continued).*

Now, we will provide you with the chance to make another choice, with much higher potential payoffs, as you can see from the sheet we are passing around. The difference between this part and all other decisions you have made and will make is that all payoffs from this round are hypothetical and will not be paid to you. The procedures are exactly as before, after you make your ten decisions, then draw from the cup once to determine which decision is to be used, and then draw a second time to determine the payoff for that decision.

Even though the earnings from this next choice larger, they are only hypothetical, and we would like for you to initial the statement at the top of the page indicating that you understand you will not be paid for the choice on that page. All other choices tonight will count towards your earnings. Let me reiterate that your choice in this part has no effect on your earnings and has no effect on what choices will be given to you subsequently; but we are interested in what you would do if you actually faced these choices, so please think about them carefully.

Figure A2. Penny Game *(continued).*

ID: _____

I understand that the earnings for the decisions I make on this sheet are hypothetical and will not be paid to me.

	Option A	Option B	Your Choice A or B
Decision 1	$40.00 if throw of die is 1 $32.00 if throw of die is 2-10	$77.00 if throw of die is 1 $2.00 if throw of die is 2-10	
Decision 2	$40.00 if throw of die is 1-2 $32.00 if throw of die is 3-10	$77.00 if throw of die is 1-2 $2.00 if throw of die is 3-10	
Decision 3	$40.00 if throw of die is 1-3 $32.00 if throw of die is 4-10	$77.00 if throw of die is 1-3 $2.00 if throw of die is 4-10	
Decision 4	$40.00 if throw of die is 1-4 $32.00 if throw of die is 5-10	$77.00 if throw of die is 1-4 $2.00 if throw of die is 5-10	
Decision 5	$40.00 if throw of die is 1-5 $32.00 if throw of die is 6-10	$77.00 if throw of die is 1-5 $2.00 if throw of die is 6-10	
Decision 6	$40.00 if throw of die is 1-6 $32.00 if throw of die is 7-10	$77.00 if throw of die is 1-6 $2.00 if throw of die is 7-10	
Decision 7	$40.00 if throw of die is 1-7 $32.00 if throw of die is 8-10	$77.00 if throw of die is 1-7 $2.00 if throw of die is 8-10	
Decision 8	$40.00 if throw of die is 1-8 $32.00 if throw of die is 9-10	$77.00 if throw of die is 1-8 $2.00 if throw of die is 9-10	
Decision 9	$40.00 if throw of die is 1-9 $32.00 if throw of die is 10	$77.00 if throw of die is 1-9 $2.00 if throw of die is 10	
Decision 10	$40.00 if throw of die is 1-10	$77.00 if throw of die is 1-10	

Decision used: _____, Number selected: _____ Your hypothetical earnings: _____

Figure A3. Emotion Regulation Questionnaire.

ERQ
SUBJECT EXPERIMENT ID: _____
DATE: _____

Instructions:

We would like to ask you some questions about your emotional life, in particular, how you control (that is, regulate and manage) your emotions. The questions below involve two distinct aspects of your emotional life. One is your emotional experience, or what you feel like inside. The other is your emotional expression, or how you show your emotions in the way you talk, gesture, or behave. Although some of the following questions may seem similar to one another, they differ in important ways. For each item, please answer using the following scale:

1----------2----------3----------4----------5----------6----------7
strongly disagree **neutral** **strongly agree**

1. ____ When I want to feel more *positive* emotion (such as joy or amusement), I *change what I'm thinking about*.
2. ____ I keep my emotions to myself.
3. ____ When I want to feel less *negative* emotion (such as sadness or anger), I *change what I'm thinking about*.
4. ____ When I am feeling *positive* emotions, I am careful not to express them.
5. ____ When I'm faced with a stressful situation, I make myself *think about it* in a way that helps me stay calm.
6. ____ I control my emotions by *not expressing them*.
7. ____ When I want to feel more *positive* emotion, I *change the way I'm thinking* about the situation.
8. ____ I control my emotions by *changing the way I think* about the situation I'm in.
9. ____ When I am feeling *negative* emotions, I make sure not to express them.
10. ____ When I want to feel less *negative* emotion, I *change the way I'm thinking* about the situation.

Figure A4. Post-experimental questionnaire for Experiments 1 through 3.

Post-experiment questions

***ID*_____ *Date* _____**

1. **How did exposure to the water make you feel?**

   1 2 3 4 5 6 7
   bad neutral good

2. **How much stress did you feel from water procedure?**

   1 2 3 4 5 6 7
   none medium very much

3. **How much pain did you feel from the water procedure?**

   1 2 3 4 5 6 7
   none medium very much

4. **How interested were you in playing the game?**

   1 2 3 4 5 6 7
   not very interested neutral very interested

5. **How did it feel when you found out you won?**

   1 2 3 4 5 6 7
   bad neutral good

6. **How did it feel when you found out you lost?**

   1 2 3 4 5 6 7
   bad neutral good

7. **How did it feel when you found out you didn't win?**

   1 2 3 4 5 6 7
   bad neutral good

Figure A4. Post-experimental questionnaire for Experiments 1 through 3 *(continued)*.

8. How did it feel when you found out you didn't lose?

1	2	3	4	5	6	7
bad			**neutral**			**good**

9. Did you use any strategies?

10. Please write any comments you may have about the experiment in general. Did you think that there were any unclear areas; can you think of any suggested improvements? Overall, how did you feel while participating? Was it fun? Was it boring? Were you distracted? Would you do another similar experiment?

Figure A5. Post-experimental questionnaire for Day 1 of Experiment 4.

Post-experiment questions

***ID*_____ *Date*_____*(Day 1)*_____**

1. **How interested were you in playing the game?**

   1 2 3 4 5 6 7
   bad neutral good

2. **Please rank the value of the squares from today's experiment, 1 being the least valuable and 9 being the most valuable.**

Yellow ____
Red ____
Blue ____
Green ____
Orange ____
Purple ____
Gray ____
Brown ____
White ____

3. **Did you use any strategies?**

4. **Please write any comments you may have about the experiment in general. Did you think that there were any unclear areas; can you think of any suggested improvements? Overall, how did you feel while participating? Was it fun? Was it boring? Were you distracted? Would you do another similar experiment?**

Figure A6. Post-experimental questionnaire for Day 2 of Experiment 4.

Post-experiment questions

***ID*_____ *Date*_____*(Day 2)*_____**

1. How did exposure to the water make you feel?

1 2 3 4 5 6 7
bad neutral good

2. How much stress did you feel from the water procedure?

1 2 3 4 5 6 7
none medium very much

3. How much pain did you feel from the water procedure?

1 2 3 4 5 6 7
none medium very much

4. How interested were you in playing the game?

1 2 3 4 5 6 7
not very interested neutral very interested

5. Please rank the value of the squares from today's experiment, 1 being the least valuable and 9 being the most valuable.

Yellow ____
Red ____
Blue ____
Green ____
Orange ____
Purple ____
Gray ____
Brown ____
White ____

Figure A6. Post-experimental questionnaire for Day 2 of Experiment 4 *(continued)*.

6. Did you use any strategies?

7. Please write any comments you may have about the experiment in general. Did you think that there were any unclear areas; can you think of any suggested improvements? Overall, how did you feel while participating? Was it fun? Was it boring? Were you distracted? Would you do another similar experiment?

Figure A7. Post-experimental questionnaire for Experiment 5.

Post-experiment questions

***ID*_____ *Date*_____**

1. **How did exposure to the room temperature arm wrap make you feel?**

   1 2 3 4 5 6 7
   bad neutral good

2. **How much stress did you feel from the room temperature procedure?**

   1 2 3 4 5 6 7
   none medium very much

3. **How much pain did you feel from the room temperature procedure?**

   1 2 3 4 5 6 7
   none medium very much

4. **How did exposure to the cold arm wrap make you feel?**

   1 2 3 4 5 6 7
   bad neutral good

5. **How much stress did you feel from the cold procedure?**

   1 2 3 4 5 6 7
   none medium very much

6. **How much pain did you feel from the cold procedure?**

   1 2 3 4 5 6 7
   none medium very much

7. **How relaxing did you find the relaxation technique to be?**

   1 2 3 4 5 6 7
   none medium very

Figure A7. Post-experimental questionnaire for Experiment 5 *(continued).*

8. How interested were you in playing the game?

1	2	3	4	5	6	7
not very interested			neutral			very interested

9. How did it feel when you found out you won?

1	2	3	4	5	6	7
bad			neutral			good

10. How did it feel when you found out you lost?

1	2	3	4	5	6	7
bad			neutral			good

11. How did it feel when you found out you didn't win?

1	2	3	4	5	6	7
bad			neutral			good

12. How did it feel when you found out you didn't lose?

1	2	3	4	5	6	7
bad			neutral			good

13. Did you use any strategies?

14. Please write any comments you may have about the experiment in general. Did you think that there were any unclear areas; can you think of any suggested improvements? Overall, how did you feel while participating? Was it fun? Was it boring? Were you distracted? Would you do another similar experiment?

Anthony J. Porcelli
Social and Affective Neuroscience Laboratory
Psychology Department
Smith Hall, 101 Warren St.
Newark, NJ 07102
917-804-1710
aporcell@psychology.rutgers.edu

EDUCATION

Rutgers University, Newark, NJ
PhD in Psychology, expected January 2009

New York University, New York, NY
Master of Arts in Psychology: Biopsychology Concentration, September 2004

Carnegie Mellon University, Pittsburgh, PA
Bachelor of Arts in Psychology and Philosophy, May 2002

ACADEMIC EXPERIENCE

Rutgers University, Newark, NJ
Graduate Student: Social and Affective Neuroscience Lab, Fall '06/Current
- Participated in the design, implementation, and statistical analysis of behavioral and fMRI experiments exploring the stress response and its impact on human cognition.
- Responsible for recruiting and working with human subjects using MRI technology.

Rutgers University, Newark, NJ
Graduate Student: Cognitive Brain Sciences Lab, Spring '03/Spring'06
- Participated in the design, implementation, and statistical analysis of fMRI experiments exploring the cognitive model of working memory.
- Responsible for recruiting and working with human subjects using MRI technology.

Nathan S. Kline Institute, Orangeburg, NY
Assistant Research Scientist:
Department of Statistical Sciences and Epidemiology, Winter '02/Spring '03
- Responsible for interviewing patients in the field at various medical facilities.
- Administered the Dartmouth Assessment of Lifestyle Inventory and the Mini International Neuropsychiatric Interview screens.

Carnegie Mellon Human-Computer Interaction Institute, Pittsburgh, PA
Research Assistant: People & Robots Project, Summer 2002
- Responsible for conducting empirical research in the area of human-robot interaction.
- Completed two experiments making use of the Nursebot project robot, involving a total of 60 participants.

JOURNAL ARTICLES

- Porcelli, A.J. & Delgado, M.R. Reward processing in the human brain: Insights from fMRI. **In press in J. Dreher and L. Tremblay (Eds.),** ***Handbook of Reward and Decision Making.*** New York: Elsevier.

- Porcelli, A.J. & Delgado, M.R. Acute stress modulates risk-sensitivity in financial decision-making. **In press in** ***Psychological Science.***

- Porcelli, A.J., Cruz, D., Wenberg, K., Patterson, M., Biswal, B., Rypma, B. (2008). The effects of acute stress on human prefrontal working memory systems. *Physiology & Behavior, 95(3),* 282-289.

- Patterson, M.D., Bly, B.M. Porcelli, A.J., & Rypma, B. (2007). Visual working memory for global, object, and part-based information. *Memory & Cognition, 35(4),* 738 – 751.

- Eldreth, D.A., Patterson, M.P., Porcelli, A.J., Biswal, B.B., Rebbechi, D. & Rypma, B. (2006). Evidence for multiple manipulation processes in prefrontal cortex. *Brain Research, 1123(1),* 145-156.

ABSTRACTS & CONFERENCE PRESENTATIONS

- Porcelli, A.J & Delgado, M.R. (2007, September). Acute stress modulates risk sensitivity in financial decision-making. *Society for Neuroeconomics*. Hull, MA.

- Porcelli, A.J., Cruz, D., Wenberg, K., Patterson, M.D., Bukowski, E., and Rypma, B. (2006, April). The Effects of Acute Stress on Human Prefrontal Working Memory Systems. *Cognitive Neuroscience Society Annual Meeting*. San Francisco, CA.

- Eldreth, D.A., Porcelli, A.J., Patterson, M.D., Botowski, E., Witham, J., Zaconne, E., and Rypma, B. (2004, October). Age related reduction of neural efficiency and cognitive performance: an event-related fMRI study. *Society for Neuroscience Annual Meeting,* San Diego, CA.

- Porcelli, A.J., Wenberg, K., Cruz, D., Patterson, M.D., and Rypma, B. (2004, October). Effects of acute stress on prefrontal working memory systems. *Society for Neuroscience Annual Meeting,* San Diego, CA.

- Eldreth, D.A., Porcelli, A.J., Patterson, M.P., Witham, J., Bukowski, E., Zacone, E., Rypma, B. (2004, October). Age-related Reduction in Neural Efficiency and Cognitive Performance: An Event-Related fMRI Study. *Society for Neuroscience Annual Meeting*. San Diego, CA.

- Eldreth, D.A., Porcelli, A., Genova, H., Patterson, M.P., Rypma, B. (2004, April). Neural Correlates of Age-Related Reductions in Processing Speed: An Event-Related fMRI Study. *Cognitive Aging Conference*. Atlanta, GA.

- Eldreth, D.A., Genova, H., Porcelli, A.J., Patterson, M.P., Rypma, B. (2004, April). Neural Correlates of Age-Related Reductions in Processing Speed: An Event-Related fMRI Study. *Cognitive Neuroscience Society Annual Meeting.* San Francisco, CA.

- Patterson, M.P., Porcelli, A.J., Eldreth, D.A., Zacone, E., Rypma, B. (2004, April). The Neural Basis of Object Working Consolidation: An Event-Related fMRI Study. *Cognitive Neuroscience Society Annual Meeting*. San Francisco, CA.

TEACHING EXPERIENCE

Rutgers University, Newark, NJ:
Lecturer:
- Physiological Psychology: Winter 2008, Summer 2007, Summer 2006, & Summer 2005
- Introduction to Psychology: Summer 2006

Rutgers University, Newark, NJ
Teaching Assistantships:
- Experimental Psychology: Spring 2008, Spring 2007, & Spring 2006
- Statistics: Fall 2007, Fall 2006, & Fall 2005

Carnegie Mellon University, Pittsburgh, PA
Teaching Assistantship:
- Social Psychology: Spring 2002

COMPUTER SKILLS

Operating Systems: MS Windows, MacOS, Linux, Unix.
Software: BrainVoyager, VoxBo, SPSS, SAS. E-Prime experimental design package.

SERVICE

Rutgers-Newark Department of Psychology
- Graduate Student Representative – Fall '06 / Winter '08
- Graduate Student Governing Association Department Representative – Fall '06 / Winter '08
- Department of Psychology Departmental Climate Committee
- Department of Psychology Information Technology Committee

ACTIVITIES & HONORS

NYU Master's Scholar Program
CMU College of Humanities & Social Sciences
- Graduated with College Honors

Psi Chi National Honor Society in Psychology
- Carnegie Mellon University Chapter

RESEARCH GOALS

In my past work, I studied the neural architecture underlying working memory (WM) processes in the human brain using both behavioral and functional MRI (fMRI) methodologies. Building on that platform, I expanded the line of research to examine the effects of acute stress on prefrontal cortical WM systems. Currently, I have been applying these techniques to the study of the relationship between acute physiological stress and decision-making processes in humans. Drawing on financial decision-making paradigms from the field of Economics as models for decision-making I have been using behavioral measures and fMRI, as well as recordings of skin conductance, in an effort to elucidate the impact of acute stress on financial decision-making. It is my goal to continue this Neuroeconomic line of research under Dr. Delgado as a postdoctoral fellow. A number of questions regarding the interaction between stress and decision-making remain unanswered. As a postdoctoral fellow in the Social and Affective Neuroscience Lab it will my goal to examine in-depth a number of these questions, including the study of different types of stress and their impact on decision-making and how different types of decisions themselves are impacted by stress.