CHAPTER 23 NEUROFINACE

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KEYWORDS: Neurofinance, neuroeconomics, neuroscience, investment psychology, research methods.

ABSTRACT

Biology can have both constructive and damaging effects on investment decision-making. Both research and clinical evidence confirms that subtle shifts in neurochemistry affect financial decision-making. These alternations in brain functioning are driven by events as mundane as the weather and as intense as images from a riot. Despite the individual nature of financial decision-making, an understanding of neurobiology can also be applied at the group level. Exogenous shocks and the endogenous environment affect both individuals and the crowds of financial decision makers of which they are a small part. The decisions of such crowds shift global asset prices. This chapter explores research into the biology of financial decision-making and demonstrates how many of the most successful financiers have built decision processes that strengthen vulnerabilities identified by neurofinance researchers.

INTRODUCTION

Behavioral finance studies describe market price anomalies and individual decision biases. Unfortunately, such descriptions of behavior have not proven amenable to generalization or predictive modeling. Neurofinance research illuminates the fundamental mechanisms that underlie how individual biases, irrational behavior, and collective buying and selling decisions emerge. Using research tools and techniques borrowed from the field of neuroscience, scientists are gaining the necessary insights to build comprehensive economic models of human economic behavior and decision-making.

Just as the field of economics provides a foundation for traditional finance, neuroeconomics research is informative of neurofinance. Neurofinance is not a separate field so much as a set of experimental techniques and tools that practitioners in many other fields adopt to investigate questions of central interest. *Neurofinance experimentation* is defined by the use of the scientific method to identify drivers and modifiers of choice behavior. Experimental apparati including neuroimaging and behavioral monitoring equipment are frequent tools of choice in such research. The use of neuroscientific research tools allows economists to look at biological drivers of decision-making. In particular, many economists are interested in investigating the origins of the non-optimal decision-making. Issues addressed by neurofinance research include: (1) financial risk-taking (both excessive and aversive); (2) expectation formation; (3) valuation; (4) information presentation and updating such as framing, reference points, and affective loading; (5) probability assessments under conditions of risk, uncertainty, and ambiguity; and (6) cooperation, competition, herding, and social influences on choice.

This chapter describes the progress researchers have made in contributing to our understanding of financial risk-taking (including concepts of utility, emotional priming, probability assessments, and reference points) and social influences on choice (including moral concepts such as reciprocity, cooperation, trust, and revenge). As such, the remainder of the chapter consists of four sections: neuroscience primer, research methods, decisions and biases, and summary and conclusions.

Neurofinance studies of human behavior under conditions of risk and reward have identified significant neural correlates with behavior in areas of the brain that are involved in motivation, emotion, self-reflection, and strategy regions. Understanding the methods of neurofinance researchers first involves reviewing basic neuroanatomy and physiology.

NEUROSCIENCE PRIMER

The human brain is the product of millions of years of evolution. It is designed to efficiently and effectively interpret information, compete in a social hierarchy, and direct activity toward achieving goals while avoiding danger. The human brain evolved to optimally interface with a stone-age world where dangers and opportunities were largely immediate, and social interactions were limited to other members of a hereditary clan. The stone-age human brain is not optimized for managing many of the informational and relationship complexities of modern economic decision-making. Thus, many of the biases identified in behavioral finance may be traced back to the brain's evolutionary development.

There are many levels of function in the brain, from the actions of individual molecules to broad communications between lobes. At a molecular level, neural activity is driven by neurochemicals, small electrical currents, genetic (protein) transcription, and epigenetic cellular milieu. On the anatomical level, neural circuits cross brain regions and give rise to complex thoughts and behaviors. These are building blocks of a neurological understanding of the brain.

In the neuroeconomic academic literature, findings of interest reference significant statistical correlations between subject biology (e.g., genetic endowment, neural activations, and personality traits) and behavior (e.g., stated preferences, buying and selling decisions, and behavior). To researchers, changes in neurophysiology (e.g., fluctuations in blood flow, electrical activity, neurotransmitter activity, and cellular metabolism) and aberrations in neuroanatomy (e.g., brain structures, hormone levels, and neurotransmitter receptors) are of interest in their relation to financial and strategic decision-making. Understanding the findings of neurofinance researchers first requires an appreciation of basic neurobiology.

The Triune Brain

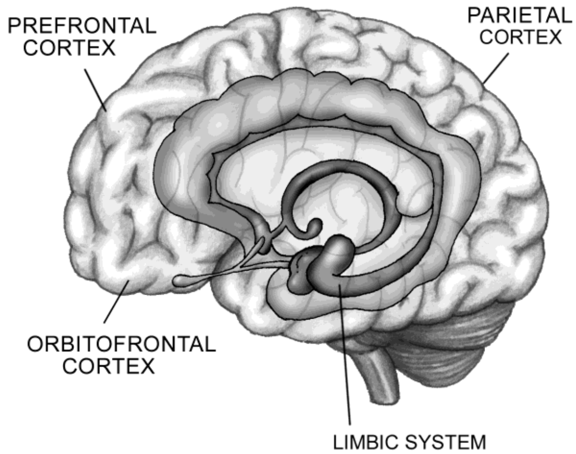
The brain can be conceptualized as having three major anatomical divisions. Each division is like the layer of an onion, with complex processes such as analytical decision-making in the outer layer, motivations and drives arising from the middle layer, and life-sustaining physiological processes originating in the innermost core. This conceptual schema is termed the “Triune” brain (MacLean, 1990).

The cortex is the brain's logistical center. It is the director of executive function and motor control. The part of the cortex called the prefrontal cortex is of most interest to this chapter. The prefrontal cortex is involved in abstract thinking, planning, calculation, learning, and strategic decision-making (Prabhakaran, Rypma, and Gabrieli, 2001). One part of the cortex, called the insular cortex, is evolutionarily distinct from the neocortex. When using the word “cortex”, this chapter broadly refers to the neocortex and the prefrontal cortex, but excludes the insular cortex.

The brain's limbic system is the emotional driver of the brain. The limbic system is the source of primitive motivations and emotions including fear and excitement. Exhibit 23.1 displays both the cortex and the limbic system. The third division of the brain is called the midbrain (also know as “the reptilian brain”). The midbrain manages the body's basic physiological processes, including respiration and heart rate, and it will not be discussed further in this chapter.

EXHIBIT 23.1 A Depiction of the Whole Brain

The limbic system is situated underneath the cortex. The prefrontal cortex lies behind the forehead. The orbitofrontal cortex (OFC) is located behind the eyes and above the sinuses. The parietal cortex is situated at the posterior of the brain.



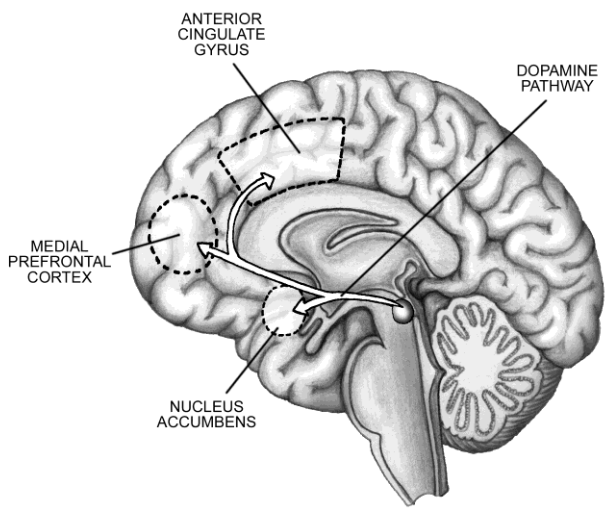
Traversing the three “layers” of the brain are neuronal pathways that deliver, integrate, and process information. Since the time of Aristotle, scientists and philosophers have loosely hypothesized the existence of two major brain functions that are fundamental to almost all human behavior: the *reward approach* (pleasure-seeking) and the *loss avoidance* (pain-avoidance) systems (Spencer, 1880). These two motivational systems can be activated or de-activated independently. When humans face potential financial gains or losses, one or both of these systems may be used in the process of decision-making. This chapter presents a review of empirical evidence of the direct link between brain activation specific to these two systems: affective (emotional and feeling) states and financial decision-making.

The Reward System

Perceiving a potential reward in the environment sets the brain’s reward approach system into action. Overall, the reward system coordinates the search for, evaluation of, and motivated pursuit of potential rewards. The neurons that carry information in the reward system transmit signals primarily via the neurotransmitter dopamine. The reward system lies along one of the five major dopamine pathways in the brain, the meso-limbic pathway as shown in Exhibit 23.2, which extends from the base of the brain, through the nucleus accumbens (NAcc) in the ventral striatum of the limbic system to the gray matter of the frontal lobes (MPFC) and the Anterior Cingulate Gyrus (ACC) (Bozarth, 1994).

Exhibit 23.2 A Depiction of the Brain's Reward System

The dopamine tract underlying the reward system extends from the midbrain through several structures key for reward valuation and motivation.



Dopamine was historically called the "pleasure" chemical of the brain. More recently, researchers have found dopamine to play a role in attention, mood, learning, motivation, and reward valuation and pursuit (among other functions). People who are electrically stimulated in brain regions with high concentrations of dopamine terminals report intense feelings of well-being (Heath, 1964). Illicit drug use activates the dopaminergic pathways of the reward system. Dopamine activity in the reward system appears to correlate with subjective reports of positive affect (Knutson, Adams, Fong, and Hommer, 2001).

On the one hand, hypoactivation or desensitization of the reward system results in a propensity to feel apathetic, have low energy, and engage in compensatory excitement and novelty-seeking behaviors such as pathological gambling and compulsive shopping. On the other hand, short-term gains energize dopamine flow in the reward circuit.

Loss Avoidance

A second fundamental motivational circuit governs “loss avoidance.” The “loss avoidance system” is activated when the brain recognizes potential threats or dangers in one’s environment. Anxiety, fear, and panic are emotions that arise from the loss avoidance system, and pessimistic and worried thoughts are the cognitive sequelae of loss system activation.

The brain’s loss avoidance system is less defined than the reward system. It runs through several regions of the brain’s limbic system, in particular, the amygdala and the anterior insula. Its activity is mediated by serotonin and norepinephrine (among other neurotransmitters) and can be modulated with antidepressant medication such as selective serotonin reuptake inhibitors (SSRIs). Acute activations of the loss avoidance system lead to the subjective experience and physiological signs of anxiety (Bechara, Damasio, and Damasio, 2000).

Activation of the brain's loss system results in stress, anxiety, disgust, pain, and even panic. The behavioral bias of loss aversion is fueled by fears of disappointment and regret, and appears to arise from amygdala activation (DeMartino, Kumaran, Holt, and Dolan, 2009). The anterior insula is an area of primitive cortex that governs the experiences of disgust, pain, and loss (Wright, He, Shapira, Goodman, and Liu, 2004). Anterior insula activation precedes excessive risk aversion in one investment experiment. The physical and mental effects of stress are generated by hormonal and chemical pathways in the loss avoidance system.

Loss system activation affects the entire body through bloodstream hormone and neurotransmitter release. The perception of a threat activates the hypothalamus-pituitary-adrenal axis (HPA axis), which results in stress hormone and epinephrine (“adrenaline”) secretion into the bloodstream. The body's sympathetic nervous system (SNS) prepares the whole body for the “fight-or-flight” response to danger with nerve signals transmitted to every major organ system. When under threat and experiencing fear, signs of SNS activation include trembling, perspiration, rapid heart rate, shallow breathing, and pupillary dilation. The SNS is also responsible for the physical signs and symptoms of panic. As discussed later in the chapter, the experience of market volatility raises cortisol (a stress hormone) levels in traders (Coates and Herbert, 2008).

Chronic activation of the loss avoidance system is indicated by the personality trait of neuroticism (Flory, Manuck, Matthews, and Muldoon, 2004). Neuroticism is characterized by risk aversion. The prevalence of neuroticism has been weakly associated with the short form (‘s’-allele) of the serotonin transporter gene, which leads to a decrease in serotonin sensitivity (Arnold, Zai, and Richter, 2004).

The brain’s insula is involved in the anticipation of aversive affective and noxious physical stimuli (Simmons, Matthews, Stein, and Paulus, 2004) and in selective disgust processing (Wright et al. 2004). Paulus, Rogalsky, Simmons, Feinstein, and Stein (2003) show that insula activation is related to risk-averse decision-making. Paulus et al. report that insula activation is significantly stronger when subjects selected a "risky" response versus selecting a "safe" response in an experimental task. Second, the researchers find that the degree of insula activation is related to the probability of selecting a "safe" response following a punished response. Third, the degree of insula activation is related to the subjects' degree of harm avoidance and neuroticism as measured by personality questionnaires.

Because the reward and loss systems influence thought and lie beneath awareness, they often direct behavior automatically through subtle (and overt) emotional influences on judgment, thinking, and behavior. Fortunately, investigators have many tools for assessing the health of the brain's reward and loss avoidance systems.

RESEARCH METHODS

Researchers use a variety of sophisticated tools to understand how the brain works. Neuroimaging is the most widely used technology for understanding decision-making among neurofinance researchers. Most of the neuroimaging studies cited in this chapter use functional magnetic resonance imaging (fMRI). Using fMRI allows researchers to visualize changes in oxygenated blood flow, which serves as a proxy for brain metabolism. fMRI can yield resolution of brain voxels as small as 1 × 1 × 1 millimeters over time intervals of one second. Positron emission tomography (PET), which is an alternative neuroimaging technique to fMRI, has a larger spatial resolution of approximately 3 × 3 × 3 millimeters and can detect changes in glucose metabolism and blood flow only when a radioactive tracer has been injected into the subject. Other less widely used imaging techniques include Magnetic Resonance Spectroscopy (MRS) and optical tomography (a brain activity monitoring technique using infrared light). Since the mid-1990s, fMRI has become the most common neuroimaging technique due to its low invasiveness, lack of radiation exposure, and relatively wide availability.

Other investigative technologies include behavioral measures, subjective reports, psychological tests, and electrophysiology. Electrophysiology involves measurements of heart rate, blood pressure, galvanic skin response (sweating), and other physical variables, many of which are indicators of reactive brain activation in limbic and midbrain regions. Pupillary eye measurements allow researchers to directly monitor the activity of the sympathetic nervous system (SNS). The SNS is involved in the “fight-or-flight” panic response.

Electromyograghs (EMGs) measure electrical activity during muscle contraction. When EMGs are used on facial muscles, very subtle states of happiness and concern can be measured. For example, analysts who are excited about an investment idea may have greater activation of their *zygomatic* facial muscles when they talk about that investment. The zygomatic muscles control smiling. The frontalis muscle on the forehead is activated by concern, revealed in a furrowed brow, and may be more active in traders during stressful market volatility.

In the 1970s and 1980s, many decision-making researchers used electroencephalograms (EEGs) for experimentation. An EEG is a test used to detect fluctuations in the electrical activity of the surface of the brain's cortex. EEGs are often used clinically to diagnose seizures. Some psychotherapists use EEGs for emotional biofeedback (so called “neurofeedback”).

Single-neuron recording techniques are very invasive and are performed primarily on monkeys and rats. Such techniques have allowed researchers to model the activity of tiny neuronal bundles, including those used while computing the expected value of various decision options (Glimcher, 2003). Genetic sequencing technologies such as the polymerase chain reaction (PCR) have revealed that genes correlate with prominent personality and behavioral traits, including financial risk-taking. Assays of blood, saliva, and cerebrospinal fluid allow researchers to measure hormones (such as those mediating trust, aggression, and the stress response) and neurotransmitters (including those involved in impulsiveness), although using current techniques saliva can only be used to measure stress hormones and for gene collection.

A research technique most often used by neurologists is the study of patients with specific brain lesions. This technique caught the interest of behavioral economists in the mid-1990s. Small brain lesions secondary to focused strokes or tumors can cause isolated impairments. These impairments can provide much information about the function of specific brain regions.

Manipulations of diet (including dietary restrictions such as branched amino acids to lower endogenous tryptophan levels) and administration of exogenous chemicals such as medications, foods, vitamins, hormones, and intoxicants (benzodiazepines, amphetamines, cocaine, tetrahydrocannabinol (THC), and alcohol) significantly affect decision-making though known neural mechanisms.

Neurofinance researchers widely use standard psychological research tools. These tools include report surveys, behavioral observation (most neurofinance experiments attempt to correlate behavioral observation with neural or hormonal activity), personality testing such as the NEO, and specific psychometric instruments including affect, depression, anxiety, psychoticism, impulsivity, and intuition rating scales.

Monitoring individual states of arousal is layered voice analysis (LVA), which can measure stress in the voice. Textual analysis of one’s stated preferences or affects may also be a useful technique in measuring and quantifying attitudes, beliefs, and affect states.

Neurofinance experiments often attempt to draw conclusions about the decision-making process, typically via correlations of observed brain activation or hormone levels with behavioral outcomes. To address the criticism that “correlation is not causation,” many neurofinance researchers are working on behavioral prediction, and many of the studies cited in this chapter focus on such prediction.

Neurofinance research relies on experimental designs that elicit value-based decision-making. Money is a useful experimental tool because it can be used as both an incentive and a punishment, and it is scalable and universally valued. Besides money, many experiments use consumer products as performance incentives. In prospective studies, the actual spending, purchasing, borrowing, and portfolio activities of subjects can be monitored in order to investigate long-term outcomes.

Psychological states such as anticipation, deliberation, learning, updating, and calculation can be measured and observed using neuroimaging techniques such as fMRI. In most cases, neurofinance researchers’ key findings are established by identifying population (group) effects, key individual differences in decision-making, and via manipulation of the information and frame of a decision task.

THE NEUROSCIENCE OF FINANCIAL DECISION-MAKING

Biological factors can influence financial decision-making. This section reviews both the exogenous influencers and the endogenous processes influencing financial decision-making.

Medications and Drugs of Abuse Alter Financial Risk-taking

If decision-making is dependent to some extent on the brain's underlying neurochemical milieu, then dietary changes, medications and illicit drugs, exercise, and other techniques shown to alter the brain's neurochemical activity could alter decision-making. Researchers have performed numerous studies with medications, which are standardized in dosage and relatively simple to administer and monitor.

Researchers have identified medications that directly alter risk/return perceptions in behavioral experiments. This should not be surprising when considering that anxiety disorders, which treated by many pharmaceuticals, are disorders of risk-perception. Rogers, Lancaster, Wakeley, and Bhagwagar (2004) report that a common high blood pressure medication in the beta-blocker family decreased experimental subjects' discrimination of potential financial losses during a risky task.

Researchers also demonstrate that drugs of abuse affect financial decisions. For example, Lane (Lane, Cherek, Tscheremissine, Lieving, and Pietras, 2005) designed an experiment in which subjects were given a choice between a certain but low-value positive expected value option ($0.01) or a zero expected value option with high return variability (the risky option). THC intoxicated subjects preferred the risky option significantly more than control subjects who had been administered a placebo. If they lost money after selecting the risky option, THC intoxicated subjects were significantly more likely to persist with the risky selection, while controls were more likely to move to the positive expected value option. Lane, Cherek, Pietras, and Tcheremissine (2004) report a similar preference and persistence with the risky option in alcohol intoxicated subjects as compared to controls.

Many members of the benzodiazepine class of medications are Food and Drug Administration (FDA)-approved for treatment of anxiety disorders. Anxiety disorders are characterized by excessive increases in risk perception and correlated decreases in risk-taking. In experimental environments, benzodiazepine administration is associated with a dose-dependent increase in financial risk-taking (Lane, Cherek, and Nouvion, 2008). Deakin, Aitken, Dowson, Robbins, and Sahakian (2004) show that a dose of the benzodiazepine diazepam (Valium) increased the number of points wagered in a risk-taking task only in those trials with the lowest odds of winning but the highest potential payoff. Lane, Tcheremissine, Lieving, Nouvion, and Cherek (2005) report that administration of the benzodiazepine alprazolam (Xanax) produced increased selection of a risky option under laboratory conditions. Interestingly, the strength of a subject's risk-seeking personality traits may be predictive of acute drug effects on risk-taking behavior. The above studies illustrate that common chemical compounds can alter an individual's propensity towards risky choice.

Financial Risk-taking and the Reward and Loss-Avoidance Systems

Kuhnen and Knutson (2005) demonstrate the roles of the reward and loss-avoidance systems in portfolio choices and investment errors. The goals of their study are twofold: (1) to determine whether anticipatory brain activity in the NAcc and anterior insula would differentially predict risk-seeking versus risk-averse choices, and (2) to examine whether activation in these regions would influence both suboptimal and optimal choices. Their evidence shows that while NAcc activation preceded both risky choices and risk-seeking mistakes, anterior insula activation preceded both riskless choices and risk-aversion mistakes. These findings are consistent with the hypothesis that NAcc activation represents gain prediction (Knutson, Fong, Adams, and Hommer, 2001), while anterior insula activation represents loss prediction (Paulus et al., 2003). Therefore, the results indicate that beyond contributing to rational choice, anticipatory neural activation may also promote irrational choice. Thus, financial decision-making may require a delicate balance—recruitment of distinct anticipatory mechanisms may be necessary for taking or avoiding risks, but excessive activation of one mechanism or the other may lead to mistakes.

Overall, these findings suggest that two distinct neural mechanisms involving the NAcc and the anterior insula drive risk-seeking choices (e.g., gambling at a casino) and risk-averse choices (e.g., buying insurance). The findings are consistent with the notion that activation in the NAcc and the anterior insula, respectively, index positive and negative anticipatory affective states, and that activating one of these two regions can lead to a shift in risk preferences. This may explain why casinos surround their guests with reward cues (i.e., inexpensive food, free liquor, surprise gifts, and potential jackpot prizes)—anticipation of rewards activates the NAcc, which may lead to an increase in the likelihood of individuals switching from risk-averse to risk-seeking behavior.

Researchers find that positively exciting environmental cues can increase financial risk-taking. Risk-taking is increased following activation of the subject's NAcc via priming with external pictures or video clips. Seeing a sexy picture activates the NAcc and makes subjects more likely to take a lower expected value gamble (Knutson, Wimmer, Kuhnen, and Winkielman, 2008a). Furthermore, having experienced a recent "win" in an investment simulation makes subjects more likely to take an "irrational" risk (Kuhnen and Knutson, 2005). In an experimental bubble, viewing an exciting video clip before trading begins increases the amplitude of the price bubble (Odean, Lin, and Andrade, 2012). Knutson, Wimmer, Rick, Hollon, Prelec, and Loewenstein (2008b) identify two clear predictors of purchasing. Activation of the NAcc demonstrated "liking" of consumer products, which predicted buying. Additionally, perceiving that a consumer item is "cheap" or "on sale" leads to activation of the MPFC, which predicts buying behavior (Knutson, Wimmer, Prelec, and Loewenstein, 2007).

The Genetics of Financial Decision-Making

In the financial markets, researchers have found genetic markers that predispose individuals to higher levels of risky financial decision-making. In a genetic study by Kuhnen and Chiao, (2009), subjects who have the DRD4 gene 7-repeat allele take 25 percent more risk in an investment task, while those with two copies of the short serotonin transporter gene (5-HTTLPR s/s) take 28 percent less risk.

In contrast to Kuhnen and Chiao's (2009) findings, Frydman, Camerer, Bossaerts, and Rangel (2010) do not identify differences in risk-taking across DRD4 allele and 5-HTT polymorphism carriers. The authors do, however, find a significant relationship with the MAOA-L gene. The MAOA gene produces an enzyme involved in catabolism of dopamine, norepinephrine, and serotonin. The abnormal variant MAOA-L is more active. Behavioral traits associated with this gene include impulsive risk-taking and aggression. Those with this gene take more financial risks, but with higher expected utility. For the above reasons, the gene has been nicknamed “The Warrior Gene.” As Frydman et al. (p. 1) note, “Our computational choice model, rooted in established decision theory, showed that MAOA-L carriers exhibited such behavior because they are able to make better financial decisions under risk, and not because they are more impulsive.”

Neurofinance researchers such as Mohr, Li, and Heekeren (2009) also find alterations in risk-taking over the lifespan, with age-related changes in financial risk-taking. For example, as a presumed result of the biological change that accompanies early life experiences and changes in dopaminergic and serontonergic transmission over the lifespan, the saving and investment patterns of people who came to age during traumatic economic events (e.g., the Great Depression or periods of low stock returns) are different from those who did not (Malmendier and Nagel, 2009). Evidence also suggests that adolescents exhibit a different neural reaction to financial advice than adults (Engelmann, Moore, Capra, and Berns, 2012). Researchers using the Swedish Twin Registry find that 25 percent of the individual variation in investment risk-taking is due to genetic factors (Cesarini, Johannesson, Lichtenstein, Sandewall, and Wallace, 2010). This genetic variation in behavior also applies to investment style choices including such specific investment products as ethical/sustainable investment products.

Disposition Effect

Several neurofinance researchers investigate the tenets of prospect theory, with examinations of the neural correlates of loss aversion, reference point setting, the endowment effect, the disposition effect, and the repurchase effect. Neurofinance researchers find that some investors are more susceptible to the disposition effect (taking excessive risk in the realm of losses) and that this increased susceptibility can be traced to specific neural activations. Personality studies identify individuals with high neuroticism scores as having more reactive anterior insulas in the context of experiencing losses. When using personality testing and neuroimaging in tandem, the accuracy of predicting which individuals will exhibit risk seeking in the realm of losses may increase.

Neuroscientists in London designed an experiment that uses framing to elicit the neural process underlying loss aversion. In an fMRI study at University College London, Benedetto De Martino recruited 20 men and women to undergo three 17-minute brain scans. At the start of each trial, the subjects received English pounds worth about $95. The researchers then asked them to make a choice between receiving a certain outcome (a gain or a loss) and taking a gamble. The gamble they could accept was a simple 50–50 bet in which they wagered a predefined amount of their money. The gamble's expected value was equivalent to that of the certain option, so there was no financial reason subjects should show a preference for either the certain outcome or the gamble (De Martino, Kumaran, Seymour, and Dolan, 2006).

When the researchers framed the choice as a decision between “keeping” a certain amount of money and gambling, most participants chose to “keep” their money. For example, when told they would “keep” 40 percent of the starting sum if they chose not to gamble (as in “Keep $38”), the volunteers typically played it safe, choosing to take the 50–50 gamble only 43 percent of the time. When told they would “lose” 60 percent of their initial pot if they did not gamble, they took the risk 62 percent of the time, even though the gambles always had the same expected value as the certain option. Interestingly, De Martino et al.’s (2006) results provide evidence that loss aversion is induced by the language used to frame a risky choice.

The subjects had the odds explained to them in detail before the experiment, and they knew that the probabilities in each situation were identical. Nonetheless, the language altered their decisions: “Keep $38” put them in a gain frame, and “Lose $38” induced a loss frame. When succumbing to loss aversion, the subjects’ amygdalas (stimulated by danger) activated vigorously. When participants resisted the framing effect, the orbitofrontal cortex (involved in integrating emotion and reason) and the anterior cingulate cortex (responsible for sorting out internal conflicts) both activated. Four of the study participants acknowledged inconsistencies in their decision-making, choosing according to the frame rather than the odds. In explaining their actions, they said, “I know, I just couldn't help myself,” according to De Martino (Vergano, 2006, p. D4).

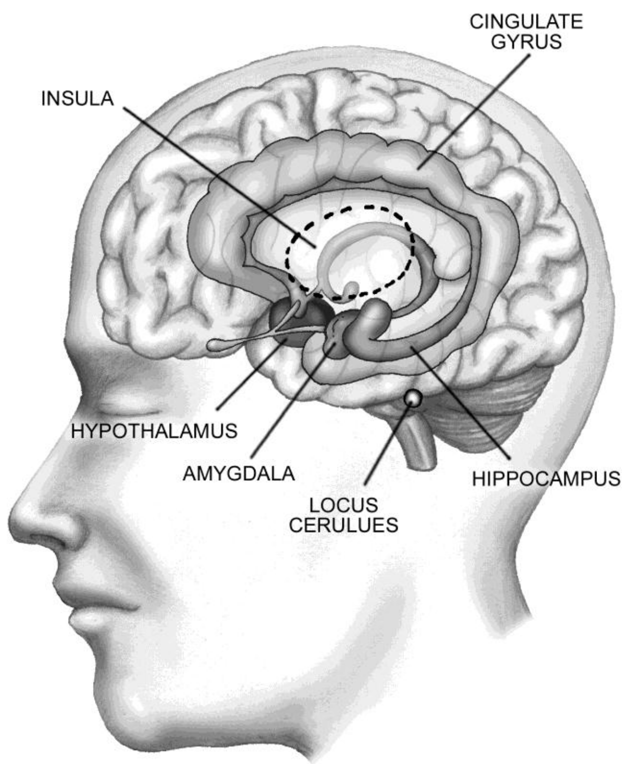
In a subsequent fMRI study, De Martino, Kumaran, Holt, and Dolan (2009) demonstrate that two distinct neural circuits activated in response to expected value computation (reference point-independent values). They also find that a reference point (in this case ownership, as seen in the endowment effect) distorted the value computation. Their results show that activity in the orbitofrontal cortex and dorsal striatum tracked parameters such as expected value. In contrast, activity in the ventral striatum (the ventral striatum contains the NAcc) indexed the degree to which stated prices were distorted with respect to a reference point.

The *disposition effect* – the tendency to be risk averse in the domain of gains (sell winners too soon) and to be risk seeking in the domain of losses (hold losers too long) – is a behavioral bias thought to result from the framing effect. A study on the disposition effect by Brooks, Capra, and Berns (2012) identifies that neural activity in the ventral striatum may represent a psychological mechanism for the disposition effect in the domain of losses. In particular, the authors find that when an asset undergoing random walk price action falls below the purchase price, individuals who show attenuated ventral striatum activation during price upticks – only when the price is below the purchase price – also demonstrate a greater disposition effect. In explanation, Brooks et al. (p. 1) assert, “for some individuals, the disposition effect is likely driven by a belief that the asset will eventually return to the purchase price...” This belief that the asset price will rise back to the purchase price accounts for the diminished reaction in the ventral striatum – the price rise was expected.

Knutson et al. (2008b) identify the right anterior insula as the brain structure whose activation is most predictive of the endowment effect as shown in Exhibit 23.3. When an individuals experience the potential pain of losing an endowed item (via selling the item) more acutely as seen in their greater activation of the right anterior insula, then they are more likely to exhibit the endowment effect by demanding a much higher sale price.

Exhibit 23.3 An Illustration of Several Structures in the Brain's Loss Avoidance System

The loss avoidance system is distributed throughout several brain structures. These underlying structures are involved in detecting, processing, learning about, and responding to potential threats.



As would be expected if a human brain evolved from those of other primates, capuchin monkeys are susceptible to loss aversion and the endowment effect (Chen, Lakshminarayanan, and Santos, 2006). Furthermore, loss aversion is not age-dependent. Human children, while unable to express gambles in terms of expected value, also demonstrate loss aversion, with no age-diminishing influence through college (Harbaugh, Krause, and Vesterlund, 2002).

In a series of detailed experiments comprising both behavioral and neural data collection, Cary Frydman and colleagues at the California Institute of Technology identify drivers of the repurchase effect among traders. The *repurchase effect* refers to a tendency for traders to buy stocks they previously owned that have declined in value and avoid buying stocks they previously owned that have gone up in value. Of the 28 experimental traders in Frydman's study, all exhibit the repurchase effect Frydman (2012).

Neural evidence reported by Frydman (2012) suggests that a regret signal – a counterfactual comparison – in the brain's ventral striatum (which contains the NAcc) drives the repurchase effect. Frydman finds that individuals with a high propensity to sell stocks with capital gains appear to have a low propensity to repurchase stocks with strong recent performance. Using a neural proxy for regret, he then identifies that this regret signal is encoded in the left ventral striatum. Frydman (p. 79) concludes that "experienced regret is a mediating factor of the inaction inertia effect," in which traders do not act to buy rising stocks they previously owned due to regret-fueled inertia. Those traders who have a stronger regret signal are predisposed to the repurchase effect – buying stocks they previously owned that have dropped, but not buying the same stocks if they have risen from the sale price.

Intertemporal Choice and Impulsivity

In experiments, most subjects discount future rewards, pursuing smaller sooner rewards rather than waiting for larger later ones, Thus, they sacrifice a rate of return on their money far greater than any they could earn via an average investment. The fact that most individuals "leave money on the table” by seeking rewards immediately rather than waiting has prompted inquiry from neurofinance researchers into the mechanisms by which such discounting occurs (also known as *hyperbolic discounting*).

Samuel McClure, a neuroscientist at Princeton University, performed a brain-imaging experiment with colleagues on volunteers engaged in a time discounting task. He gave subjects several decision pairs and asked them to state their preferences between them. For example, they could choose between an Amazon.com gift certificate worth $20.28 today and one worth $23.32 in one month. In a longer-term example, researchers asked subjects to, for example, choose between $30 in two weeks and $40 in six weeks (McClure, Laibson, Loewenstein, and Cohen, 2004).

McClure et al. (2004) find that time discounting results from the combined influence of two neural systems. Limbic regions drive choices in favor of immediately available rewards. The frontal and parietal cortices are recruited for all choices. These two systems are separately implicated in emotional and cognitive brain processes, and a competition appears between the two systems during discounting-type decisions, with higher limbic activation indicating a greater likelihood that immediate gratification will be pursued.

McClure et al. (2004) also find that when experimental subjects choose larger delayed rewards, cortical areas such as the lateral and prefrontal cortex show activity enhancement. These brain regions are associated with higher-level cognitive functions including planning and numerical calculation. McClure's theory is supported by a finding that in prisoners the cortical regions activated by delayed gratification are thinned. This may explain why their decisions are more often short-sighted than others (Yang, Raine, Lencz, Birle, LaCasse, and Coletti, 2005). According to McClure et al. (p. 506), “Our results help to explain why many factors other than temporal proximity, such as the sight or smell or touch of a desired object, are associated with impulsive behavior. If limbic activation drives impatient behavior, it follows that any factor that produces such activation may have effects similar to that of immediacy.” According to McClure et al., immediacy in time may be only one of many factors that, by producing limbic activation, engenders impatience and impulsive action.

Researchers find that temporal discounting may be a result of dual competing valuation mechanisms in the brain. In one circuit, the reward system values the magnitude of potential gains, while in the other network, the dorsolateral prefrontal cortex and other structures deactivate in response to the delay that must be experienced (Ballard and Knutson, 2009).

The delay of a potential reward introduces uncertainty. Uncertainty decreases financial risk-taking, especially when it is associated with ambiguity in payout probability or outcome magnitude, and the difference between uncertain versus ambiguous financial risks can be seen and tracked in neural activation patterns (Hsu, Bhatt, Adolphs, Tranel, and Camerer, 2005).

Beyond impatience for financial rewards, a study of dieting finds that gastronomic impulse control appears to be based in circuitry shared with financial prudence. Self-control appears to be biologically modulated by a value signal encoded in ventromedial prefrontal cortex (vmPFC). Exercising self-control involves the modulation of that value signal by the dorsolateral prefrontal cortex (DLPFC) (Hare, Camerer, and Rangel, 2009). Unfortunately, like a muscle that becomes tired from overwork, practicing self-control depletes cognitive resources for future self-control. During periods of high cognitive load – multitasking or complex problem solving – external support prevents common errors. Neuroscientists find that financial advice reduces cognitive load of individuals in an investing task (Engelmann, Capra, Noussair, and Berns, 2009). For this reason, individuals may seek financial advice afterwards despite little evidence of financial benefit. The benefit of financial advice is in freeing up cognitive and emotional energy so that it may be expended elsewhere. In the case of selecting retirement savings accounts with varying penalties, individuals who are self-aware of their own weak self-control voluntarily increase punishments if they break their own savings agreement. Presumably they take this irrational action to prevent making choices they will later regret.

Emotions and Testosterone in the Trading Pit

Several researchers gather neuroecononomic data directly from traders. Lo and Repin (2002) take psychophysiological measurements from 10 traders during real-time intra-day trading and find that traders experience physiological reactions during periods of market volatility. The study also shows that less experienced traders have significantly greater physiological reactivity to market volatility than their more experienced colleagues. Lo and Repin (p. 332) conclude, "Contrary to the common belief that emotions have no place in rational financial decision-making processes, physiological variables associated with the autonomic nervous system are highly correlated with market events even for highly experienced professional traders."

Coates and Herbert (2008) sample, under real working conditions, endogenous steroids from a group of male traders in the City of London. They report that a trader's testosterone level at 11 a.m. correlates with trading profitability over the remainder of the day. They also find that a trader's cortisol rises with both the variance of his trading results and the volatility of the market. Their results suggest that higher testosterone may contribute to economic return for traders, whereas cortisol appears to increase under conditions of increased risk perception. The authors postulate that testosterone and cortisol, because they are known to have cognitive and behavioral effects, may shift risk preferences and even affect a trader's ability to engage in rational choice as market conditions change.

Building on evidence that prenatal (in-utero) exposure to sex hormones (specifically androgens) affects future behavior, Coates, Gurnell, and Rustichini (2009) perform a follow-up study on the second-to-fourth digit length ratio (2D:4D), where a relatively longer fourth finger indicates higher prenatal androgen exposure. In a group of male traders engaged in what is variously called "noise" or "high-frequency" trading, the authors find that 2D:4D predicts the traders' long-term profitability as well as the number of years they remain in the business. 2D:4D also predicts the sensitivity of their profitability to increases both in circulating testosterone and in market volatility. In terms of profitability, the top one-third of the traders in terms of 2D:4D are 11 times more profitable than the bottom third.

The authors conclude that prenatal androgens increase risk preferences and promote more rapid visuomotor scanning and physical reflexes. The success and longevity of traders exposed to high levels of prenatal androgens further suggests that financial markets may select for biological traits rather than rational expectations.

The results of the above studies suggest that hormonal exposure, whether in-utero or in real-time as a result of market events, apparently affects profitability and risk-taking. This hormonal evidence contributes to understanding neuroimaging data. Testosterone may increase dopamine secretion, such as that seen in fMRI experiments above, thus leading to increased financial risk-taking through a neural mechanism.

Gender Differences In Neurology and Financial Behavior

While studies show that testosterone and cortisol levels affect financial decision-making in male traders, researchers have not directly studied the relationship between female trader biology and performance. However, the menstrual cycle appears to change how women deal with risky situations. While men may be more hormonally reactive to specific external events and competitive pressures, women have an internal hormonal cycle that significantly alters their risk-taking and emotional state independent of external events. Phases of the menstrual cycle correlate with different risk-taking in some studies, but not all studies on this topic have congruent findings. The risk-taking differences that occur over the female menstrual cycle appear due to hormone-modulated neural activity in the brain (Dreher, Schmidt, Kohn, Furman, Rubinow, and Berman, 2007).

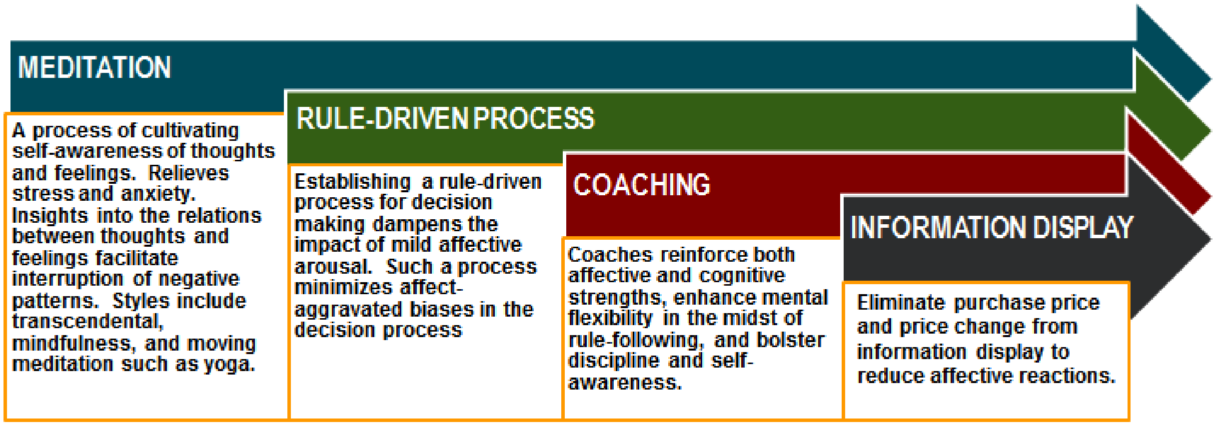
THE IMPLICATIONS OF NEUROFINANCE RESEARCH FOR PRACTITIONERS

Currently no evidence-based decision tool based on neurofinance research is available to improve individual investment decision-making. Numerous technical limitations constrain the real-world application of tools such as fMRI and facial EMG for trader decision-making. Genetic studies, which may provide valuable insight into risk management style, remain controversial and demonstrate disparate findings. Electrophysiologic monitoring devices, some of which have been commercialized for traders, have not yet been empirically shown to increase trader performance. Psychopharmaceutical interventions such as psychostimulants (e.g., amphetamine derivatives) and hormone augmentation (e.g., testosterone) have numerous side effects and no clear benefits for the average financial decision maker.

As Lo and Repin (2002) and Coates and Herbert (2008) demonstrate, professionals are physiologically reactive and release stress hormones (cortisol) in response to market volatility, which changes cognition and in some cases increases biased decision-making. Many decision makers find the development of an analytic process and the presence of a human coach to improve their decision-making and financial outcomes. Several behavioral interventions to moderate innate affective responses are summarized in Exhibit 23.4 and summarized below. Additionally, several cognitive practices reduce the deleterious cognitive effects of reactive hormones including reframing, self-awareness, and reappraisal, all of which are discussed in this section and outlined in Exhibit 23.5.

Exhibit 23.4 An Outline of Behavioral Strategies to Manage Affective Reactions and Improve Financial Decision-Making

Successful financial practitioners use strategies such as meditation, establishing a rule-driven process, using a coach, and altering information display to reduce emotional (affective) arousal and resulting misjudgments.



Meditation, peaceful reflection, and contemplation are disciplines used for millennia to manage reactive mental states via self-awareness. Evidence supports the value of self-awareness in improving trader performance. For example, Biais, Hilton, Mazurier, and Pouge (2002, p. 3) find that "highly self-monitoring" traders perform better than their peers in an experimental market. While noticing affect states is important, avoiding placing any value judgment on them is crucial. Many of the most successful practitioners in the financial industry, including Ray Dalio, Chief Executive Officer (CEO) of Bridgewater Associates, the largest hedge fund in the United States, and Bill Gross, CEO of PIMCO, the largest fixed income fund in the world, use daily meditative practices to cultivate self-awareness. Dalio practices transcendental meditation, and Gross practices Ashtanga yoga. Financial practitioners may practice noticing the thoughts, feelings, and attitudes that underlie their decision-making and notice the deleterious patterns in their behavior. Once these patterns are conscious, people can make plans for avoiding or eliminating their impact.

Many hedge funds use performance coaches with clinical psychology and psychiatry training who can respond dynamically to trader needs with clinical affective and cognitive interventions across circumstances. For example, Steve Cohen, billionaire CEO of SAC Capital – one of the consistently most successful hedge funds in the world - employed Ari Kiev, M.D.

(now deceased) as an in-house performance coach for himself and his portfolio managers for over 15 years. Paul Tudor Jones, CEO of Tudor Investment Corporation, employs clinical and academic psychologist Brett Steenbarger Ph.D., who specializes in trader psychology and short-term therapies, to coach Tudor portfolio managers and traders. Many other examples of such in-house coaches in the financial industry are available.

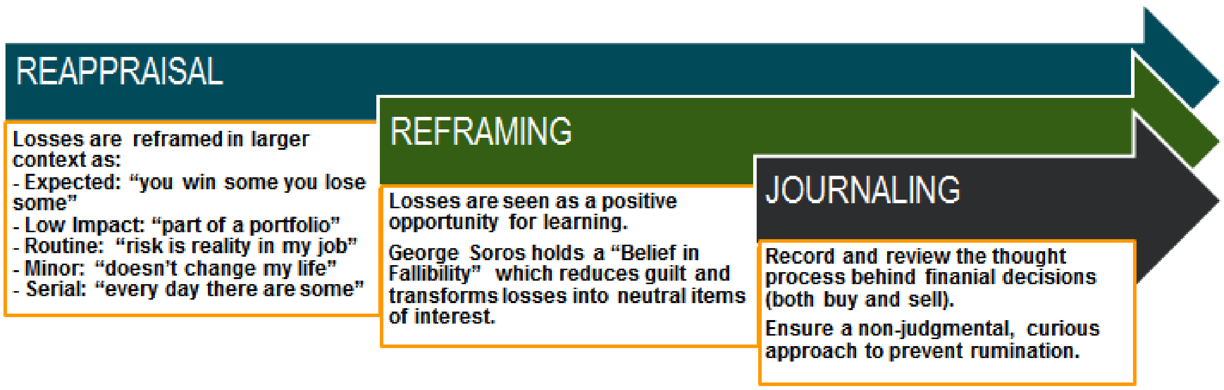
Many successful financial practitioners such as Dalio systematize as much of their decision-making process as possible. Dalio and Bridgewater are well-known for their Principles, a collection of written ethos which employees are expected to model. Dalio's firm follows simple macroeconomic investment rules that are designed to pre-empt decision biases from adversely influencing analyst judgment and portfolio manager decision-making. Such rule-following approaches provide distance between the decision maker and the decision outcome, thus reducing the negative impact of losses on judgment biases.

How information about investment returns is displayed significantly affects trading behavior, presumably through its impact on affect and arousal and the subsequent exacerbation of cognitive biases. Fortunately, the display of information can be optimized to reduce biased trading (Frydman, 2012). Displaying the original purchase price of a stock and its recent change in value increased the repurchase bias in an experimental market. Frydman (p. 111) offers the following prescription in contrast to current regulatory policy: "If regulators stipulate that brokerage houses decrease the saliency of the capital gain by removing the cost basis from the regular financial statements (as in our cost basis treatment), this would likely attenuate the disposition effect, and could increase individual investor trading performance."

In addition to the above behavioral strategies to improve affect management, several cognitive interventions are available for improving decision quality, as seen in Exhibit 23.5. A decision journal is a common tool for recording and reviewing feedback about decision-making patterns over time. As in mediation, a decision journal improves self-awareness by making conscious the relationships among feelings, thoughts, and behaviors. The challenge with a journal is maintaining a non-judgmental perspective on past losses and gains because reviewing past losses itself can create an adverse response. For this reason, a journal is best utilized after establishing a meditation practice and one can reframe losses as positive feedback for learning.

Exhibit 23.5 An Outline of Cognitive Strategies for Strengthening Financial Decision-Making

Research shows that cognitive strategies including reappraisal, reframing, and decision journaling can reduce financial decision biases.



Neuroscientific evidence supports the practice of reframing realized financial losses as intellectual gains. George Soros is one of the most celebrated traders in market history, and he finds that reframing results from a "Belief in Fallibility." Soros (1995) explains that to others being wrong is a source of shame. But for Soros recognizing his mistakes is a source of pride. Soros explains that realizing that imperfect understanding is the human condition leads to no shame in being wrong, only in failing to correct our mistakes.

Researchers find that cognitive "reappraisal" reduces the impact of loss aversion on decision-making (Sokol-Hessner, Hsu, Curleya, Delgado, Camerer, and Phelps, 2009). *Reappraisal* refers to taking a perspective of a situation along several dimensions. Consider that in an experimental condition, researchers randomly ask subjects to think of their individual investments under the following conditions: (1) as part of a portfolio, (2) as one of many in a series, (3) as part of a routine job, (4) as expecting that loses are going to happen “you win some and you lose some,” and (5) as not having direct consequences to their lives. In aggregate these cognitive reappraisals reduce both physiological reactions to losses (measured via galvanic skin response) and subsequent loss-averse behavior. According to Sokol-Hessner et al, (p. 1), ‘‘‘perspective-taking,’ uniquely reduced both behavioral loss aversion and arousal to losses relative to gains, largely by influencing arousal to losses.”

SUMMARY AND CONCLUSIONS

While biological predispositions affect the human mind, neurofinance is an emerging discipline whose key findings need replication and comprehensive modeling. Examples of biologically mediated influences on financial decision-making discussed in this chapter include medications, drugs of abuse, hormones, dietary restrictions, dietary additions, expert financial advice, massage, recent events (gains and losses), early life events, and framing decision options.

Important critiques of neurofinance address the lack of experimental replication of many early findings. Neurofinance studies are often expensive. Many researchers push the boundaries of existing decision science rather than replicating the studies of colleagues.

Another critique focuses on sample sizes and composition. Because fMRI and other techniques are expensive and research funds can be difficult to procure for novel research, many fMRI studies use small samples of 20 or less. The subjects in these studies are typically students. Given observed differences in the biological substrates of decision-making over the lifespan, results found on young samples may not be confirmed for older individuals. Additionally, researchers draw most subjects from university student bodies, which may not reflect the learning and experience of professional financial decision makers.

Another concern is the ultimate utility of neurofinance research. Findings from very specific studies may not represent noisy real-world decision-making. Can neurofinance findings scale up to reliably explain collective decision-making be used to develop public policy, and be employed in financial trading, product marketing, and educational fields among many others? Furthermore, some express concern that neurofinance thinking is too "reductionistic". The criticism goes that neurofinance researchers try to explain and model human behavior based on small pieces of data and anatomical findings, without taking the entire complex person, with all their conflicts, contradictions, and mixed motives into account.

As this chapter explains, neurofinance comprises an interdisciplinary approach to the question of how behavioral and cognitive biases influence investor behavior. Perhaps most importantly, recent neurofinance research has begun to unravel how the psychological and physical environment of financial decision makers can be modified to optimize financial decision-making. Many of the most successful financial practitioners in history including George Soros, Ray Dalio, Bill Gross, and Steve A. Cohen evolved decision strategies that strengthen decision vulnerabilities now identified as such in neurofinance research.

DISCUSSION QUESTIONS

1. As compared to classic studies in behavioral finance, how does neurofinance achieve additional explanatory power over non-optimal financial decision-making?
2. Biologically speaking, what are some brain structures and chemicals that influence financial decision-making?
3. What techniques, supported by neurofinance, do successful financial practitioners use to improve their performance?
4. Identify the major criticisms of neurofinance research.

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