Decision Making, Financial Risk Aversion and Behavioral Biases: The Role of Testosterone and Stress

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Abstract
This study examines testosterone and cortisol levels of finance graduate students participating in three investment trials. The trials involve a portfolio asset allocation task with the last trial also including a series of rebalancing tasks in an increasingly competitive environment. Their testosterone and cortisol levels are positively correlated with financial risk in a competitive environment. However, testosterone is also positively related to more diversified portfolios. Specifically, higher testosterone participants choose higher risk asset allocations to earn a higher risk premium, but also chose more diversified portfolios to reduce unsystematic risk. Lastly, task success leads to higher levels of post-trial testosterone.

Keywords: testosterone, cortisol, physiology, stress, risk aversion, disposition effect

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1. Introduction

To what extent does a person's physiology impact his (her) financial decision making? Finance professionals typically ignore this question. To help answer it, we examine how levels of the sex hormone testosterone and the stress hormone cortisol affect financial decision making.[1] The current body of research (summarized below) demonstrates that testosterone plays a key role in decisions involving economic risk and reward. In particular, testosterone is thought to exert a significant influence on the cognitive processes that deal with the interpretation of financial information, risk preferences, and investor confidence (Coates et al., 2010). Therefore, testosterone levels can have important repercussions for our financial decisions and the resulting investment outcomes. Additionally, it is widely held that stress is rampant among finance professionals, including traders and fund managers, and scholars have found a clear connection between stress and cognitive processes. Yet the specific role of stress on financial choices and outcomes has only recently been addressed, and then only by a limited number of studies.

The present study represents one of the first comprehensive efforts to understand the role of both testosterone and stress on financial decision making. The nature of their roles is not well understood. For example, it is not known whether testosterone or stress influence every kind of financial decision (such as long-term investing versus day trading), or if their effects are limited to a particular subset of financial decision-making tasks, like competitive bidding (Schipper, 2014). Moreover, although we do not know the specific nature of the relation between our physiology (i.e., hormone actions), cognitive biases, and financial performance, we are confident that cognitive biases lead to irrational choices that can affect financial performance. However, financial success or failure could potentially impact the physiology of the investor, creating a

[1] Cortisol is secreted by the adrenal glands into the blood in response to stressful stimuli. Therefore, the circulating level of cortisol (versus cortisol that is stored in the adrenal glands) is the primary biological marker of stress.

feedback loop. Therefore, a link from the stock market back to investors might be a critical component for feedback models of stock market bubbles, yet little research has been conducted on this aspect of the decision-making process.

Most studies examine the relations between testosterone or stress and economic risk from a static framework. That is, studies assume that the relations between either testosterone or stress and economic risk are constant for different tasks. However, we know that some activities, such as poker tournaments, can impact a person's physiology, including hormone levels. Therefore, physiology could play different roles in financial decisions, depending on the context of the decision – for example, investing decisions versus speculative decisions such as trading. Therefore, the relations between testosterone or stress and economic risk are likely to be dynamic ones, in which the influence of testosterone and cortisol changes depending on the context of the risk-taking activity, including whether it is goal oriented or completion oriented, and on the prior levels of success.

In this study, we investigate the role of testosterone and cortisol on financial choices and outcomes during two single decision points, portfolio formation (asset allocation) tasks and one multipoint portfolio rebalancing task. These tasks involve financial decision making for long-term investments using a financial trading simulation application. We find that higher levels of testosterone and stress increase risk taking through the selection of higher risk asset allocations that earn higher risk premiums. Alternatively, their asset allocations are also associated with more diversified portfolios, which means lower unsystematic risk. Therefore, the positive association between testosterone and risk in other contexts (such as social decisions) turns out to be more nuanced for financial decisions. Consequently, financial risk decisions are not speculative risk (because of increased diversification), but rather calculated to earn a higher expected return

(through riskier asset allocations). We also find that higher testosterone levels are associated with the selection of more risky portfolios than are necessary to meet the desired investment goals. Subjects with higher testosterone levels attempt not only to achieve the financial goals required, but also to perform well compared to their peers. Lastly, we find a relation between financial performance and changes in testosterone: Subjects who performed better in the simulation increased their level of testosterone relative to those who performed poorly. Therefore, we find that testosterone level impacts participants' financial decisions, and the outcome of those decisions then impacts testosterone levels.

The remainder of this paper is organized as follows. Section 2 reviews the literature on the influence of testosterone and cortisol on financial risk aversion. Section 3 describes our methods and three trials. Specifically, we discuss our subjects, the trials, investment simulations, and saliva testing. Section 4 reviews the results for the first asset allocation task. The results from the second asset allocation task are shown in Section 5. The final trial, the rebalancing task, is reported in Section 6. Our discussion of the results can be found in Section 7.

2. The Literature and a Discussion of Factors Affecting Decision Making

2.1. Testosterone and Financial Decision Making

Only a few studies have addressed the effect of testosterone on financial decision making, leaving much to be explored. Three important issues that remain poorly understood are: 1) How does testosterone affect financial outcomes (such as investment risk and expected return)? 2) Is testosterone related to behavioral biases like trend following or loss aversion? 3) Are testosterone levels impacted by financial trading and competition? The reminder of this section describes the extent to which these questions are addressed in the literature to date.

The literature on the relation of testosterone to financial decision making is concentrated in a few recent studies. Coates and Herbert (2008) and Coates et al. (2009) find evidence for a correlation of testosterone levels with financial decision making. Coates and Herbert measure morning (11:00 a.m.) and afternoon (4:00 p.m.) testosterone levels in a small group (n=17) of male traders for eight consecutive business days under real working conditions. The authors find that traders achieve a significantly greater daily profitability (profit and loss level, or P&L) on days when their morning testosterone level is above their overall median level over the course of the study. These results show that morning testosterone levels can partially predict the direction of daily profitability in traders. Similarly, Coates, et al. (2009) measure the length ratio of the second digit finger to the fourth digit finger ratio (2D:4D) of 44 male high-frequency traders and find it to be predictive of the traders' P&L levels over a 20-month period. The 2D:4D ratio is directly related to the amount of in utero testosterone exposure.[2] Therefore, the results offer the possibility that prenatal testosterone levels are associated with the long-term profitability of high-frequency traders.

The Coates and Herbert (2008) and Coates et al. (2009) studies show evidence that testosterone is related to financial profitability in trading activity, providing a partial answer to the question of how testosterone affects financial outcomes. However, they do not find a relation between testosterone and financial risk taking. This finding (or rather lack of) is curious, given the empirical evidence linking testosterone to a variety of social behaviors involving risk, such as a higher likelihood of committing a violent crime among male prison inmates (Dabbs et al., 1987), drug use, aggressive violence and high-risk sexual behavior among anabolic steroid users (Middleman and DuRant, 1996), and antisocial and deviant behavior among male U.S. Army

[2] An alternative physical measure used by Jia, Lent, and Zeng (2014) employs characteristics of a person's face to create a facial masculinity index in order to examine masculine behaviors in financial misreporting.

veterans (Mazur, 1995). Nevertheless, the medical literature shows that monetary incentives and other kinds of rewards are processed by different areas in the brain areas (Knutson et al., 2001). Therefore, the results in Coates and Herbert (2008) and in Coates et al. (2009) are consistent with the view that *financial* risk taking is not related to testosterone levels, because of the unique way in which the brain perceives and responds to financial risk.

Apicella et al. (2008) investigate the link between testosterone and financial risk preferences in a sample of men. Participants are asked to bet any desired amount of money from an original $250 endowment in a coin-toss gamble. A winning toss returns 2.5 times the amount wagered, whereas a losing toss forfeits the amount of the bet. The authors show that salivary testosterone level (Sal-T) is positively correlated with the amount bet in the gamble. As such, the results show that endogenous testosterone levels are related to financial risk preferences in men. In contrast, Sapienza et al. (2009) measure risk aversion using the algorithm from Holt and Laury (2002) in a task where subjects make choices between a risky lottery and varying certainty equivalents that provide a guaranteed return.[3] They find that salivary testosterone is associated with lower risk aversion among women, but not among men. As such, Apicella et al. (2008) and Sapienza et al. (2009) provide conflicting results as to whether a relation between testosterone levels and risk aversion actually exists. However, their conflicting results could be due to the way that each study measures risk aversion. Note that in Apicella et al. (2008), the risk measure is purely speculative risk, since no risk premium reward exists for a 50/50 coin toss. Alternatively, Sapienza et al. (2009) use a series of gambles that vary the risk premium. Ahern, Duchin, and Shumway (2014) also use the Holt and Laury (2002) risky lotteries that vary the risk premium and

[3] Holt and Laury (2002)'s algorithm is a method to measure the degree of risk aversion. Subjects are presented with a menu of paired lottery choices that are structured so that the crossover point to the high-risk lottery can be employed to infer the level of risk aversion.

find that peer effects impact a person's financial risk aversion. However, Ahern et al. (2014) only examine risk aversion and social characteristics, and do not examine physiological characteristics. Apicella, Dreber, and Mollerstrom (2014) use the risky lotteries to examine financial risk taking after trying to influence testosterone levels through a chance-based competition. After the competition, participants completed the lottery survey. They find that changes in testosterone predict greater financial risk taking.

Studies in which participants are administered testosterone exogenously (i.e., orally or intravenously) also have yielded inconsistent results. Van Honk et al. (2004) show that women who are given exogenous testosterone exhibit decreased risk aversion during the Iowa Gambling Task (IGT). These results are consistent with Stanton, Liening, and Schultheiss (2011), who show that endogenous testosterone levels are positively associated with risk taking in the IGT among men and women. Alternatively, Goudriaan et al. (2010) fail to show that men with supra-physiological levels of testosterone perform differently in the IGT. Similarly, Zethraeus et al. (2009), using a version of Holt and Laury's (2002) algorithm, fail to show that testosterone administration in women is associated with financial risk preferences. Therefore, similar to the studies analyzing the relation between endogenous levels of testosterone and financial risk taking, studies using exogenous measures of testosterone fail to provide consistent results.

Stanton, Liening, and Schultheiss (2011) propose that the inconsistent results from studies examining the relation between testosterone and economic risk are due to the nonlinear effect of testosterone on economic risk. In particular, they show that endogenous testosterone levels have a U-shaped association with financial risk preference and ambiguity preference, but not with loss aversion.[4] Thus, both men and women with intermediate levels of testosterone were found to be

[4] Ambiguity preference describes the preference toward known risks and unknown risks. As such, an ambiguity-averse individual prefers known-risk situations over unknown-risk situations. Importantly, ambiguity describes situations

risk- and ambiguity-averse, whereas those with low and high testosterone were found to be risk- and ambiguity-neutral.

The inconsistent results found throughout the literature could also be due to the fact that studies use a variety of different tasks to measure economic risk, use either laboratory or real-life settings, examine active choices or survey responses, measure either endogenous or exogenously manipulated levels of testosterone, and/or include either one or both genders.

Because of the difficulties associated with replicating real-life economic incentives in the laboratory, several studies prefer to examine investor behavior in their natural environment. However, the nature of the financial task itself can explain why studies of this kind (e.g., Coates and Herbert, 2008; Coates et al., 2009), do not find that testosterone levels are related to financial *risk taking* in professional traders. In addition, testosterone could be related to financial speculating tasks in ways that are different from its relation to financial investing tasks. Coates and Herbert (2008) and Coates et al. (2009) use a sample of traders, whom by definition engage in very short-term financial decisions. At this level of decision making, factors other than testosterone can play a larger role in the risk undertaken by individuals. The time pressure that pervades day trading is present to a much lesser degree in other kinds of financial tasks, such as long-term investment planning. Thus, we can intuitively link the pressure to quickly produce results during day trading to high stress, which could outweigh the influence of testosterone on risk taking during trading. Lastly, Jia, Lent, and Zeng (2014) examine the facial masculinity of CEO's as a proxy for masculine behaviors and posits that testosterone influences both face shape and corporate decisions in finance and accounting. They find that more facial masculinity is positively associated

where outcome probabilities are unknown. Alternatively, risk aversion describes situations where outcome probabilities are known (see Epstein, 1999).

with misreporting, and therefore the greater likelihood of an SEC enforcement action, insider trading, and option backdating.

Finally, only a few studies examine the question of how testosterone levels influence financial decision making. This is perhaps the most difficult question to answer, because it involves understanding the biochemical mechanism of testosterone action in the brain. In general, testosterone is thought to influence financial decision making by shifting economic utility functions, confidence levels, and/or risk preferences, through its effect on the brain's nucleus accumbens. As a part of the dopamine system, the nucleus accumbens is associated with pleasure as well as irrational, risk-seeking behavior (Kuhnen and Knutson, 2005).[5] Therefore, it is possible that testosterone could be related to financial cognitive errors, given that many behavioral biases also involve emotions. Evidence of the "rewarding" property of testosterone is also found in addiction studies of humans taking anabolic steroids (Kashkin and Kleber, 1989).[6] However, we are aware of no studies that examine the relation of testosterone to behavioral biases in decision making.

2.2. Stress and Financial Decision Making

Occupational stress is particularly high among finance professionals (Jones et al., 2003), and it can result in behavioral problems, such as mental disorders (Dias, 1997) and elevated alcohol consumption (Kahn and Cooper, 1990). Oberlechner and Nimgade (2005) surveyed a large sample

[5] Dopamine is the major neurotransmitter of the reward system of the brain, which includes the ventral tegmental area, the nucleus accumbens, the amygdala, the hippocampus, and the medial prefrontal cortex. Rewarding experiences such as food, sex, and drugs lead to the release of dopamine, providing feelings of enjoyment and motivating the reinforcement of these activities. Bressan and Crippa (2005) provide a basic review of the dopamine system and its role in reward and pleasure.

[6] This rewarding property is thought to be due to the effects of testosterone and its two metabolic byproducts (dihydrotestosterone (DHT) and estradiol) on the nucleus accumbens, causing an increase in dopamine release (Frye et al., 2002).

of foreign exchange traders (n=326), showing that "pressure to achieve the profit goal" is reportedly the greatest source of stress, followed by "long working hours" and "time pressure." These results are not unexpected, and they do not provide finance professionals with useful solutions. For one, the aforementioned sources of stress are part of the job requirements for traders; therefore they cannot be mitigated. Additionally, self-reported information fails to address stress sources that are outside of an individual's awareness. For example, Lo and Repin (2002) show that traders exhibit changes in heart rate, blood pressure, and skin conductance concurrently with transient market events. Such instinctual physiological responses to financial stimuli are consistent with the experience of stress. Therefore, biological markers of stress, such as cortisol levels, provide a superior method to study the relation between stress and financial decision making.

Salivary cortisol (Sal-C) is the preferred method used by researchers for measuring circulating levels of cortisol in the body, due to the noninvasiveness of this approach. Coates and Herbert (2008) examine the relation of Sal-C to financial performance in a small sample of male floor traders (n=17). The authors find no evidence that cortisol levels are related to trading gains or losses (P&L). Instead, they show that cortisol levels possess a significant positive linear relation to standard measures of risk, such as the variance of profits and the volatility of the market. In addition to the standard measures of risk, the present study considers various other risk measures and risky choices. We choose alternative measures because standard measures of risk are suboptimal predictors of risk preferences (Weber, Shafir, and Blais, 2004). Additionally, some studies show the opposite relation between stress and risk taking as described by Coates and Herbert (2008). For example, Van Honk et al. (2003) show that cortisol levels correlate positively with risk aversion (instead of risk taking) in subjects playing the Iowa Gambling Task (IGT).

Similarly, Kandasamy et al. (2014) find that subjects who are administered cortisol during a period of eight days exhibit greater levels of risk aversion than a control group.

Due to the embryonic state of the literature on this subject, it is premature to draw any conclusions from Coates and Herbert (2008). However, their study is the closest available for comparison to the study here, although our study differs in the following key respects: We analyze the relation of cortisol to financial decisions made both during investing tasks and competitive tasks. Moreover, we use a sample of male *and* female naïve financial decision makers, whereas Coates and Herbert only employ a sample of male professional traders. Therefore, the results of the present study are easier to apply to a broader range of investors than the results provided by Coates and Herbert. Finally, this study is free of trader selection bias, as we do not exclude subjects on the basis of their (lack of) trading skills. Such bias occurs in the Coates and Herbert study because even the least experienced professional trader is carefully selected from a large pool of applicants on his/her merit as a "good" trader.[7] Individual professional traders should also be able to cope with trading-related stress better than the average individual investor. Note that the lack of a relation between cortisol levels and trader P&L levels in the Coates and Herbert sample could be the result of the superior stress-coping skills of individuals in their sample.

3. Methods[8]

This study follows a similar methodology as other studies on the relation of endogenous testosterone and cortisol levels to economic behavior. That is, subjects provide demographic information as well as a saliva sample before the trials that is used to measure their levels of testosterone and cortisol. After subjects provide the initial saliva sample, they engage in three

[7] It is common practice to put applicants through trading simulations and trial periods before hiring them as traders.
[8] Prior to conducting the study we obtained Institutional Review Board (IRB) approval from the Office of Research (Protocol Approval #IRB-13-003).

financial trials using trading and investment simulation software. A second saliva sample then is obtained at the end of the trials. Finally, we examine the impact of testosterone and cortisol levels on financial decision-making and risk-taking behavior via statistical analysis.

3.1. Subject Recruitment and Preparation

In order to employ participants who possess a superior knowledge base in finance (as compared to the average person) subjects were recruited from graduate students in a financial software course, in which they learn to use the financial trading simulation application Rotman Interactive Trader 2.0 (RIT 2.0).[9] Table 1 shows the sample statistics of the participants. Panel A identifies a final sample of 39 graduate students, with 12 women (31%) and 27 men (69%).[10] The cultural make-up of the participants includes 12 who identify as Asian, 3 as Black, 17 as Hispanic, and 7 as Caucasian. Panel B shows that the average age of the participants is 27.4 years old, with a median of 25.3. More than half of the participants have no real-life investing experience.

In order to ensure that participants were proficient users of RIT 2.0, the trial was scheduled at the end of the course, after participants had gained sufficient experience with RIT 2.0.[11] Participants were given access to the simulation case descriptions employed in the study on the course website several weeks prior to the trial. Therefore, participants who were interested in performing well in the trial prepared by reading the cases and using the accompanying Excel spreadsheet to understand the cases in advance. There were two incentives for the participants; a

[9] The simulation software was developed at the BMO Financial Group Finance Research and Trading Lab (the Rotman Finance Lab) at the University of Toronto's Joseph L. Rotman School of Management). With the permission of the instructor, study participants were recruited during the second week of the course. Potential participants were then provided a general description of the study and told what was expected of them, including that they would be expected to provide saliva samples. However, participants did not know what was being tested for in the saliva.

[10] Forty-eight students agreed to participate in the study and signed consent forms. However, several students dropped out before the simulation, two did not provide saliva samples, and the computer system did not capture one student's performance.

[11] After the trial, participants were asked to rate their level of comfort using RIT 2.0, on a scale of 1 (lowest comfort) to 5 (highest comfort). The median response score is 4, showing that most participants had a high degree of comfort.

monetary reward and a grade impact. Participants were told these incentives right after they provided the first saliva sample. The top risk-adjusted performances received the traditional monetary incentive.[12] Also, to increase participants' level of stress during the tasks, they were told that their overall risk-adjusted performance could influence their course grade by up to one-third of a grade. In a post-trial questionnaire participants were asked to rate their preparation for the trial on a scale of 1 (lowest) to 5 (highest). The median score is 4, showing that most participants believed they achieved a high degree of preparation for the trial. Additionally, 34 (87%) participants reported using the Excel spreadsheet to prepare for the portfolio formation task.[13]

3.2. The Trial

One week before the trial, participants were given a printout with detailed preparation instructions. This same handout was posted to the Blackboard Learn online course interface. Since testosterone follows a circadian rhythm, with the highest levels exhibited during the morning hours, the trial was conducted in the morning.

Participants were instructed to arrive at the computer lab facility by 8:15 a.m. on the day of the trial, and to refrain from eating or drinking anything after 8:00 a.m. on that day, in order to provide a clean saliva sample. The trial began at 8:20 a.m. and lasted for one hour. Saliva samples were collected immediately before the trial, using a standard procedure.[14] After the trial, the saliva

[12] In total, six people received gift cards.

[13] During the week before the trial, participants were reminded via an online announcement to review the study instructions and simulation cases, and they were asked to take a short online questionnaire to test their knowledge about the instructions and the simulation cases. Thus, every measure was taken to ensure that participants knew in advance what to expect during the trial. By the day of the trial, 37 (95%) participants had completed the online questionnaire. The median score is 5 (out of 6 questions), showing that the majority of participants were very familiar with the trial instructions and the simulation cases.

[14] The procedure can be summarized as follows: Each subject was provided with a Salivette® test tube at the time of collection. All subjects were given sugar-free gum in order to stimulate saliva production. Subjects produced a minimum sample of 3 ml of saliva, which they inserted into the test tube. The test tubes were sealed and refrigerated within 48–72 hours of collection at –20°C until analysis. The timespan between saliva collection and refrigeration does not influence hormonal concentration, as saliva can last up to five days on average before it degrades.

samples were transported to a Florida International University lab facility, were the salivary testosterone (Sal-T) and cortisol (Sal-C) levels were measured via mass spectrometric analysis.[15]

3.3. The Investment Simulations

Immediately following the collection of the saliva sample, participants engaged in three financial tasks using RIT 2.0.[16] The first two tasks involve investment asset allocation decision making (i.e., long-term financial choices), whereas the third task involves long-term investment decision making with the prospect of rebalancing the portfolio. The first two investment tasks are identical to each other, and they are categorized by Rotman as "Diversification." The participant is asked to allocate portfolio funds among investment assets with different return and risk characteristics. Henceforth, these tasks are referred to as the Portfolio Allocation 1 (PORT1) and Portfolio Allocation 2 (PORT2) tasks.

During the diversification tasks, subjects have an endowment of $500,000 to invest in a portfolio of assets. The stated goal is that the portfolio must grow to $1.5 million by the end of the simulated 20-year time horizon. Therefore, this task is a straightforward goal-oriented investment task. The subjects can choose from five Electronic Trading Funds (ETFs) of different historical returns and volatilities (shown in Table 2). Each participant made asset allocation decisions during

[15] The procedure for mass spectrometric analysis can be summarized as follows: To 1000 µL of saliva add both methanol Internal standard (Testosterone D_3) 1 ng; Cortisol-D_4 2 ng/100 µL. The samples are mixed with 4 ml of ethyl acetate, agitated for 15 minutes, and then centrifuged at 3000 rpm for 10 minutes. After the aqueous layer is frozen, the ethyl acetate layer is isolated. The solution is evaporated using a centrifugation evaporator. The extract is dissolved in 100 µL of 70% acetonitrile, and 10 µL of this solution is injected into the LC/MS/MS system. A parallel solid phase extraction (SPE) process using 1 ml 30 mg HLB cartridges is used instead of organic extraction. Here 1000 µL of the saliva sample is used, fortified with the corresponding internal standard and centrifuged at 3000 rpm. The supernatant is subject to SPE analysis using a mix of water and methanol, and the final methanolic extract is evaporated and reconstituted in the mobile phase for further mass spectrometric analysis. Simultaneous Testosterone, Testosterone-D_3, Cortisol and Cortisol Dd_4 are determined using selective reaction monitoring (SRM) of the following transitions (m/z): 289.3→97.3, 292.3→97.3, 363.3→327.1, and 367.3→331.3, respectively. For quantification purposes, at least five levels of calibration are use in the pg/µL range, using an internal standard.

[16] The cases were developed by the Rotman Finance Lab to be used with the RIT simulation software. Case descriptions are available for download from at the Lab's website for subscribers. Additionally, instructors have access to the case solutions and to the master Excel spreadsheets that allow each case to be tailored as needed.

the first task, PORT1. After making their allocation choices in the ETFs (or in CASH for funds not invested), each of the ETF prices evolved as a random walk with positive drift and standard deviation as given by their historical return and volatility. We are interested in examining how testosterone and cortisol influence risk aversion in this first diversification task. The price paths during any trial of the game can be significantly different from any other trial. Also, the price path of one trial has no impact on the price path of another trial, just as the previous result of a coin toss has no impact on the distribution of outcomes of the next coin toss.

For the second task, PORT2, participants see the results of the first task (PORT1) simulations. They not only see whether they met their goal, but also their ranking within the group. The monetary reward is based on the performance ranking of each task separately.[17] The knowledge of their ranking after the first task increases the competitive component for PORT2. The portfolio return outcome from PORT1 should not have an impact on the next independent decision task (PORT2), because it is the same task. However, people frequently make the cognitive error of overweighting recent and irrelevant information. This recency effect (Nofsinger and Varma, 2014), extrapolation bias (Bailey et al., 2011), and gambler's fallacy (Rabin, 2002) are common behavioral finance biases. Therefore, we are interested in examining the impact of testosterone and cortisol levels in decisions to change the allocation for the PORT2 task after considering the results of the PORT1 simulation and learning the competitive aspect of the trials.

The third task of the diversification trial involves the same initial asset allocation task, but also includes three portfolio rebalancing tasks (at years 5, 10, and 15). In this case, the portfolio outcome during each five-year simulation period does provide important information for

[17] The three top performers of each task, as measured by the Sharpe ratio, were selected and ranked as follows: the top performer earned a score of 3, second place scored 2, and the third-place performer scored 1. The scores on all tasks were added and the top six scorers got gift cards. The card value for the top three was $50 and was $25 for the second three.

rebalancing. Specifically, the value of the portfolio after each simulation is an important determinant in choosing an appropriate asset allocation to best achieve the stated goal to accumulate $1.5 million within 20 years. However, the actual performance of each asset during a simulation has no impact on their return in the next five-year period. Therefore, those results do not provide useful information to the participants. We examine the role of testosterone and cortisol in the portfolio rebalancing decisions.

3.4. Testosterone and Cortisol Measurement

Free (unbound) saliva testosterone (Sal-T) and cortisol (Sal-C) measurement is the preferred method to study circulating levels of testosterone and cortisol in the body because of the noninvasiveness of the procedure used to collect the saliva.

However, unlike blood analysis, there is no standard way to measure the Sal-T concentration. Therefore, benchmarking is constrained by the particular procedure used to determine the concentration of Sal-T. In other words, it is difficult to compare absolute levels of Sal-T across studies because of the different methodologies used to test for concentration. Only within study are comparisons useful. Therefore, we let the sample statistics dictate what constitutes high, intermediate, and low levels of Sal-T in subjects. Another aspect of testosterone measurement to consider is the fact that testosterone, being the primary male sex hormone, is many times higher in males than in females. In this sample, the mean Sal-T concentration was 30.0 pg/mL (SD=17.0) in men and 7.4 pg/mL (SD=9.1) in women.[18] Due to the natural gender difference in testosterone level, we convert individual raw Sal-T levels to z-scores relative to the Sal-T distribution for the gender of the individual. This technique is employed by other studies

[18] Stanton et al. (2011) obtains mean salivary testosterone levels of 86.5 pg/mL (SD=26.0) for men and 14.2 pg/mL (SD=7.0) for women. These levels are very different from the ones in this study, illustrating the difficulties in benchmarking Sal-T using different protocols and results from other studies.

that use a sample of mixed genders (e.g., Mehta et al., 2008). The z-scores are used for all the analyses.

We also convert individual raw Sal-C levels to z-scores relative to the Sal-C distribution for the gender of the individual. The mean Sal-C concentration in the sample is 5.48 nmol/L (SD=3.07) in men and 8.55 nmol/L (SD=8.47) in women. There is no benchmark to compare these levels, since the Sal-C measurement is strongly related to the particular technique employed. Even studies that measure Sal-C at the same time of day present significantly different Sal-C concentrations. For example, Laudat et al. (1988) measure Sal-C at the same time of day as the present study. However, their sample exhibits a mean Sal-C level of 15.5 nmol/L (SD=0.8), which is much higher than the mean Sal-C of subjects in the present study. In fact, the Laudat et al. study shows that subjects with adrenal insufficiency (abnormally low levels of cortisol) have a mean Sal-CO level of 7.5 nmol/L (SD=0.4), which is more congruent with the results of this study.[19] Due to these inconsistencies in the literature, raw levels of cortisol are standardized (converted to z-scores) in this study for all participants. The z-scores are used in all the analyses, making it easier for other studies to compare their results to this research (as long as they too standardize raw cortisol levels). The testosterone and cortisol z-scores are correlated at a value of 0.18.

4. First Portfolio Allocation Task Analysis

4.1. Asset Allocation Choices

Table 2 shows the sample statistics for the first portfolio allocation task. Participants begin with $500,000 in cash and are given the goal of concluding the 20-year simulation period with at least $1.5 million. As the subjects are graduate students in finance, they should have no trouble in

[19] Therefore, if we were to compare the Sal-C from this study with theirs, it would show that the subjects in this study suffer from abnormally low levels of cortisol.

assessing that they need to earn an annualized return of at least 5.65%. They are given the six choices of assets and their historical returns and volatility shown in Table 2, Panel A. For example, the HOME asset return in the simulation will be randomly drawn from a distribution that has an expected return of 8.5% and a standard deviation of 18%. The riskiest asset is GROW, which has an expected return of 13% and a volatility of 30%. The other assets are BOND, MINE, MMKT, and CASH. Note that CASH offers no return, whereas MMKT offers a low return with nearly no risk. The participants do not know the exact correlations between the asset returns; they only know whether correlations are high, low, or none.

The average allocation of the 39 portfolios into HOME is nearly 22%. The average allocation to the GROW asset is 24%. Allocations to BOND, MINE, MMKT, and CASH are 12.8%, 13.8%, 7.0%, and 20.5%, respectively. Panel B shows that most of the portfolios are diversified into at least five of the six assets.

The participants did select portfolios that have an expected return, on average, exceeding the minimum need of 5.65%. The average expected portfolio return is 6.53%. Measuring the risk selected by the participants is not straightforward. If the subjects knew the correlation between assets, they could compute the portfolio volatility using the historical volatilities of the assets, the correlations, and their allocation to each asset. However, they do not know the correlations. Therefore, we use estimates of portfolio risk using information known at the time of the decision. We can consider the expected return to also be a measure of risk based on the fundamental finance concept of the positive relation between expected return and risk for a diversified portfolio. Next, we compute an average volatility similar to the expected return computation by employing volatility in place of return,

$$\text{AVE VOL} = \delta_{HOME} \times 18\% + \delta_{GROW} \times 30\% + \delta_{BOND} \times 8\% + \delta_{MINE} \times 16\% + \delta_{MMKT} \times 1\%, \qquad (1)$$

where δ_x signifies the fraction of the portfolio invested in asset x. Panel C of Table 2 shows that the average AVE VOL for the portfolios is 14.45%.

Lastly, the extent of diversification attempted by the participants can be considered a measure of risk, since the participants know that diversification reduces risk. Like Cronqvist and Siegel (2014), our first measure of diversification is the number of assets purchased for the portfolio. Panel B of Table 2 reveals the distribution of the number of assets for the participants. By this measure, most of the portfolios appear well diversified. Another variable of interest is the sum of the squared weight allocated to each asset, as used in Blume and Friend (1975) and Nofsinger and Varma (2013), which measures the portfolio concentration. This variable is analogous to the Herfendahl-Hirschmann Index, which is commonly used to assess industry concentration. The higher the value, the more concentrated the portfolio; thus, the less diversified it is. Panel C of Table 2 shows that the average sum of the squared allocations is 0.347, a relatively low value that is consistent with diversification.

4.2. Testosterone and Cortisol Impacts on Diversification Choices

In order to examine the relation between testosterone and diversification choices we regress the financial decision on the testosterone z-score. Both the form of this relation and whether gender plays a role is unclear in the literature. Stanton, Liening, and Schultheiss (2011) report that the relation might include a quadratic testosterone term. Therefore, we estimate a regression model using the testosterone z-score, the squared z-score, and a dummy variable to identify female subjects. To examine the relation between cortisol and financial decisions, we estimate similar regressions by employing cortisol z-scores, squared z-scores, and the female dummy indicator variable. Lastly, we include a regression that includes both the testosterone and cortisol z-scores.

We begin our discussion of the results by examining the expected return selected by the subjects. In Panel A of Table 3, the Expected Return selected from the asset allocation is regressed on the hormone level variables. The results show that testosterone is negatively related to expected return. The saliva testosterone z-score (Sal-T) coefficient is −0.759 and is significant at the 10% level in the first model. Moreover, the coefficient is significant in the expanded model. However, the coefficients in the expanded model are not significant for the squared z-score or the Female indicator. The estimate for the cortisol z-score is −0.693 (significant at the 10% level).[20] These results show that in this investing context, higher levels of testosterone are associated with lower levels of expected return. In addition, higher levels of cortisol (or stress) are associated with lower levels of expect return. Moreover, as expected return can be interpreted as a measure of risk in a diversified portfolio, higher levels of testosterone and cortisol are associated with lower risk.

The other measure of risk we employ is the average volatility of the portfolio selected. Panel B of Table 3 shows the relation between average volatility and testosterone and cortisol. The results are similar to the expected return results. The coefficient for the testosterone z-scores is negative and significant in both the individual variable and the extended model regressions. The cortisol coefficient is negative and significant in the single variable regression. No other coefficients are significant. Again, we conclude that subjects with higher levels of testosterone and stress choose lower risk in this initial experiment.

Our next two analyses examine the influence of testosterone and cortisol on the diversification efforts of the subjects. The two diversification variables we employ are the number of assets in the portfolio and the sum of the squared allocations. Panel C of Table 3 reports a weak

[20] When the squared z-score and Female variables are added, the results show that their coefficients are not significant. In addition, whereas the z-score variable coefficient increases to −0.799, the p-value statistically drops to 0.14. When both the testosterone and cortisol z-scores are included together in the regression, both retain their negative coefficient, but neither is significant. However, with only 39 observations, the power of our models is low.

and negative relation between cortisol and diversification. The higher the stress, the lower the number of assets selected. Panel D of Table 3 examines the effect of the sum of squared allocations, with higher values reflecting a more concentrated portfolio. These results show a positive relation between the cortisol z-scores and the sum of squared allocations. Therefore, more-stressed subjects pick more-concentrated portfolios. The results of these two analyses are consistent, i.e., subjects with higher cortisol choose portfolios with lower diversification. Alternatively, testosterone does not appear to be related to the diversification variables.

5. Second Diversification Task Analysis

5.1. Financial Decisions

After the subjects made their first diversification decision, the simulation produced the yearly returns on their selected portfolio over the 20-year investment period. The subjects then reviewed those asset returns and their final portfolio value. Panel A of Table 4 shows the Expected Return and Volatility of each asset from the first task. Comparing the Expected Return to the Realized Return for each category shows that HOME, BOND, and MINE underperformed by 0.64%, 2.54%, and 1.57%, respectively. GROW outperformed its expectations by an annualized 4.28%. Thus, in general, the subject portfolio did well. For the subjects, 34 of the 39 portfolios met the goal of generating $1.5 million at the end of the simulation, with an average final portfolio value of $3.8 million. The subjects also reviewed the portfolio values of the other participants and their relative rank. Consider that one participant met the goal with a final portfolio of $1,981,584 and yet was ranked 33rd among the 39 subjects. This adds a competitive aspect to the second task.

After reviewing the results of the first task, the subjects repeated the portfolio allocation task. The second portfolio allocation task is exactly the same as the first. The trial begins with a $500,000 portfolio with the same goal as before. Since most subjects selected an asset allocation

that achieved the goal for the first trial, a reasonable expectation is that they will choose the same allocation in the second task. However, only five of the subjects selected the same allocation for the second task as they did for the first one. These average asset allocation decisions are also provided in Panel A of Table 4. Comparing these averages to those of the first task shows that the differences in allocations are significant for every asset except for MMKT. The new allocation to CASH is significantly lower and the other allocations are significantly higher. So, even though most subjects met the goal in the first task, they increased allocations to riskier assets for the second trial.

Panel B of Table 4 provides the distribution of the number of assets selected for the second task. These selections are similar to the distributions in the first task. Panel C of Table 4 shows the new allocation expected return and associated risk. The new expected return is 7.62%, which is significantly larger than the Task 1 expected return of 6.53%. This is consistent with the subjects taking more risk in the second task and is confirmed by the significant increase in the average volatility of the portfolios selected. Additionally, the sum of squared allocations is lower in the second task, showing less (average) concentration and more diversification in the portfolios.

5.2. Testosterone and Cortisol Impacts on Changes in Financial Decisions

We next examine the relation between the decision to change asset allocations for the second diversification task and testosterone and cortisol levels. Even though nearly all the subjects achieved the portfolio goal in the first task, and the second task is identical, the portfolios selected possessed a significant increase in expected return. Therefore, we examine whether the change in expected return is related to the z-scores of the hormones in Panel A of Table 5. The univariate analysis with testosterone z-scores shows that its coefficient is significantly positive at the 10%

level.[21] The coefficient for the cortisol z-score is significant and positive in both the univariate and multivariate regressions. These results show that subjects with higher levels of testosterone and cortisol increase the expected return for the second task. The results for the other measure of risk, the change in average volatility, are very similar (see Panel B of Table 5). We conclude that a *change* to a higher risk level for the second task is associated with having both higher testosterone and higher stress levels. The only difference between the setup of the two tasks is that a more competitive environment could be operative for the second task.

We examine the relation of a change in the degree of diversification and the hormone z-scores in Panel C of Table 5. Specifically, we employ the change in the sum of squared allocations as the dependent variable to measure diversification. The coefficient for the univariate testosterone z-score is negative and significant at the 5% level. The significance moves to the squared z-score coefficient in the multivariate regression. The results for the cortisol z-scores are very similar. The coefficient for the cortisol z-score is negative and significant at the 5% level, whereas the significance moves to the squared cortisol z-score in the multivariate model. Overall, the results show that higher levels of testosterone and stress are associated with changes to more diversified (less concentrated) portfolios.

Lastly, we examine the influence of testosterone and cortisol on the propensity for the existence of the extrapolation bias (trend following). The GROW asset has the highest expected return and in the first diversification task earned the highest return in the simulation, an annual return that was higher than expected. In the second task, all the assets have the same return distribution as in the first task. However, 21 out of 39 subjects increased their allocation to GROW for the second trial. Panel D of Table 5 shows the regressions for the change in allocation to

[21] When the squared z-score and Female indicator variables are included, the p-value decreases to 0.14.

GROW. Only one coefficient is significantly different from zero in this regression, i.e., the univariate cortisol coefficient is positive. This is weak evidence that subjects with more stress have a propensity for the extrapolation bias.

The results of the simulation for the returns in the second diversification task undoubtedly were disappointing to the subjects. All the risky assets performed lower than their expected return, and the GROW asset lost nearly half of its value over the 20 years. As a result, none of the subjects' portfolios achieve the $1.5 million goal.

6. Rebalancing Task Analysis

6.1. Trading Decisions

In the first two trials, subjects completed "set it and forget it" investment tasks. That is, they made asset allocation decisions, and then witnessed the 20-year simulation results. In the last trial, the subjects had three opportunities to rebalance their portfolios. Specifically, subjects set their initial allocations exactly as they did in the first two trials. The software then simulates the asset returns for years 1–5. After the fifth year, the subjects are able to buy and sell assets to modify their portfolios to take into consideration their progress to date (REBAL1). The software then simulates the returns for years 6–10. The subjects subsequently are able to rebalance again (REBAL2). Finally, the subjects rebalance after the returns are known for years 11–15 (REBAL3). The final results are known after the simulation is completed for years 16–20.

A casual examination of the rebalancing reveals several interesting facts. First, two of the subjects always rebalanced back to their initial percentage asset allocations. The rest rebalanced to different allocations. Figure 1 shows the return dynamics at each stage in the rebalancing task. The overall allocation decisions required all the subjects to obtain a 5.65% compounded return over the 20-year period. The portfolios the subjects selected at the outset were expected to earn an

average return of 7.38%. After five years of simulated returns, the average realized portfolio return was 5.62%. This means that the portfolios needed to earn 5.67% on average over the next 15 years to achieve the goal. The average expected return selected during REBAL1 was 7.32%. Things became more interesting during REBAL2. The simulated returns for years 6–10 resulted in an average portfolio realized return of 8.60%. This means that the subjects only needed to earn an annualized 4.27% during the final 10 years. However, the portfolios selected show an average expected return of 7.21%. Thus, the average subject took on more risk than needed. The subsequent average realized return for years 11–15 was only 1.62%. This result requires an average portfolio return for the final five years of 7.04%. However, the subjects selected an average expected return of only 6.69%. Three of the subjects had achieved the $1.5 million final portfolio value at the end of year 15. One of the three reallocated to 88% in the MMKT asset. The other two kept a high level of risk, with expected return of 8.55% and 9.72%. Consequently, the participants as a group did not take on enough risk during the REBAL3 decision point. Overall, the subjects do not appear to make large enough changes at decision points REBAL2 and REBAL3 to respond to the prior simulation results, and achieve the final goal.

We are interested in three aspects of the trading adjustments; adjustments to portfolio risk, the buying or selling of losers, and the buying or selling of winners. The analysis of the adjustments to portfolio risk continues our previous investigation of investment risk. The latter two analyses examine two important investment biases: loss aversion and trend following.

We begin by examining the risk taken during the four decision points (initial allocation and the three rebalancing allocations). Risk is defined as the expected return selected with the asset allocation decision, minus the return needed to achieve the final portfolio goal, which we call Excess Expected Return. For example, at the initial allocation, all the subjects need to achieve a

5.65% return annually to achieve the goal. The excess expected return is the expected return of the portfolio less 5.65%. After the first five years of simulated returns, the subjects see the realized returns and can make adjustments to their allocations. If they realized a return different from the 5.65% needed, then they could adjust the allocation. For example, if their portfolio return was only 4% annually, then they would need a compounded 6.2% return for the remaining 15 years to achieve the goal. For that subject, we compute the excess expected return at the REBAL1 decision to be the expected return from the rebalanced portfolio less 6.2%. Similarly, we compute the excess expected return at the REBAL2 and REBAL3 decision points. Therefore, we have 156 data points (39 subjects × 4 decision points) for this analysis.

Panel A of Table 6 shows a regression model of the Excess Expected Return on both hormone z-scores, both squared z-scores, the Female indicator variable, and three dummy variables for the three rebalancing decision points. The results show that the linear testosterone z-score coefficient is significantly positive at the 10% level. This shows that higher levels of testosterone are associated with higher levels of risk taking than are required to reach the goal.

We next examine loss aversion by analyzing the reallocations after an asset class loses money during any five-year simulation period. Two instances exist when an asset has a negative return during the first five-year simulation; namely, the BOND and MINE assets earned an annual compounded return of −0.75% and −4.48%, respectively. We examine whether the subjects bought, sold, or just held the asset immediately after these poor returns.[22] Of the 76 decisions to buy/sell/hold these two losing assets, 19 were to sell shares and 57 were to purchase shares. This action appears to be inconsistent with the disposition effect (Odean, 1998), which is the result of loss aversion. The disposition effect predicts that investors will hold losing positions in order to

[22] Two portfolios did not have any allocation to MINE. Since those subjects could not sell that asset, we omitted them from this analysis.

avoid the feeling of regret from realizing the loss. However, in this trial, a majority of participants bought more of the losing asset rather than simply holding on to their current position. We explain this finding by noting that this task focuses on portfolio issues like asset allocation, portfolio risk, and portfolio expected return to meet a final portfolio value goal. In other words, this task is framed to focus more on the portfolio and less on individual assets. Lim and Kumar (2008) show that the disposition effect is greater when subjects are narrowly focused. Thus the broad focus of the portfolio level may not be conducive to the disposition effect.

Panel B of Table 6 shows the regression of the amount transacted (positive values are buys and negative are sells) at REBAL1 for these two losing assets. The dependent variable is the amount bought or sold as a percentage of the starting portfolio value. The results show that the cortisol z-score is positively and significantly related to such transactions. This shows that subjects with higher levels of stress purchased more of the losing assets. This is consistent with a rebalancing technique that sells winners to buy losers.

Lastly, we examine the buying or selling of the best-performing asset in the five-year period subsequent to the next rebalancing decision. The best performing asset during the years 1–5 simulation was HOME, with a 14.98% annualized return. The GROW asset has the highest returns for years 6–10 and years 11–15, with returns of 12.92% and 5.50%, respectively. There are 117 decisions to buy/sell/hold these winners (39 portfolios × 3 rebalance decisions). For the instances of holding a winner asset, 20 of the subjects purchased more and 93 sold at least some shares. Clearly, most of the subjects did not exhibit a trend-following behavior. Instead, they appear to sell some of the winner asset to allocate money to the other assets. We estimate our regression model using these transactions for these winner assets. Panel C of Table 6 shows no significant coefficients for the variables of interest.

6.2. The Impact of Investment Outcomes on Testosterone and Cortisol

Most papers that study behavioral finance explore the impact of irrational psychological influences on trades and portfolio positions. A few of the many examples are the disposition effect (Lim and Kumar, 2008), home bias (Coval and Moskowitz, 1999), and overconfidence (Hilary and Menzly, 2006). Research shows that outside events can impact the sentiment of investors and influence stock markets, even if no logical association exists. A few examples are sporting event outcomes (Edmans, Garcia, and Norli, 2007), sunshine duration (Hirshleifer and Shumway, 2004), and the winter blues (Kamstra, Kramer, and Levi, 2000). However, very few papers explore the relation in the opposite direction. That is, does the stock market impact the psyche of investors? One notable exception is Engelberg and Parsons (2013), who find a link between hospital admissions and large stock market declines.

Biologists also have discovered that male primates (including humans) experience elevated levels of testosterone during situations of physical challenge. For example, athletes show increased testosterone levels during competition, and testosterone levels increase further after winning an event (Gladue, Boechler, and McCaul, 1989). Therefore, winning and losing contests could impact a person's testosterone level.

A few minutes after the final simulation results of the third task was known, our subjects contributed another saliva sample for testosterone and cortisol testing. We converted their hormone levels to z-scores using this sample and computed the change in z-score from this end-of-experiment measurement to the beginning measurement. The subjects saw their final portfolio results as well as a performance ranking for all the subjects. Therefore, the rebalancing task produced two outcomes: the final portfolio value and the ranking among the other subjects. The simulated return during years 16–20 were poor. The result is that only seven out of the 39 subjects

met the final portfolio goal. We employ two variables that capture the level of success of the subjects. The first is the total return realized during the rebalancing task. This variable has a competitive nature to it, as it allows a ranking with the other subjects. The second is a dummy variable of 1 for subjects who met the final portfolio goal.

Table 7 reports regressions where the dependent variables are the changes in testosterone (Panel A) and the changes in cortisol (Panel B). The independent variables are the Total Return or Met Goal dummy variables. The results show that the coefficient for Total Return is positive and significant at the 5% level for testosterone and a positive coefficient for Met Goal, although the latter p-value is only 0.136. The results show that doing well in the competition of investing increases the subject's testosterone. The results for the change in cortisol show that higher total return and meeting the goal is associated with higher stress, although the p-values do not reach traditional significance levels. We interpret our results in this section as direct evidence that the outcomes of investing decisions can impact the hormone level of investors.

7. Discussion and Conclusions

What is the role of testosterone and cortisol in financial investing and speculation? What is the role of taking risk and competing in relation to the level of testosterone and cortisol? Our evidence shows that these relations are dynamic throughout the trading process.

In the beginning of the first task, the subjects set their asset allocation decisions in the first diversification trial. The results show a negative relation between testosterone and cortisol levels with the financial risk taken. We also find somewhat mixed results (both positive and negative correlations, depending on the measure) in the relation between testosterone and cortisol in the level of diversification selected.

However, after the subjects review the first diversification task results, they repeat the same task. These results revealed whether each participant achieved the final portfolio value and how the participants were ranked. At this point, the participants are more likely to feel a higher level of competition than during the first task. Our analysis of the allocation choices for the second task shows that testosterone and cortisol are positively related to the level of investment risk selected. Thus, once in "competitive mode," higher levels of testosterone and stress increase risk taking. However, this increase in risk taking was associated with a more diversified portfolio. Therefore, the choices might not show an increase in reckless risk, but rather in calculated risk.

Our last task involves a series of rebalancing choices. We examine the level of risk taken at each of the four decision points in this task by comparing the expected return selected to the return needed to achieve the portfolio value goal. We find that higher testosterone levels are associated with selecting more risky portfolios than needed to meet the investment goals. This result is consistent with the hypothesis that subjects with higher testosterone levels possessing personal goals to perform well compared to their peers.

Our participants include both males and females. Based on our methodology, a high level of testosterone "for a woman" is registered as a high level in our sample. We find no difference in men and women in the relation between hormone levels and financial risk aversion.

We do not find a reliable link between hormone levels and behavioral biases, like the disposition effect or the extrapolation bias. Indeed, these biases do not appear to occur in our trials. We conclude that because we labeled our tasks Portfolio Allocation and Rebalancing, our participants were directed to focus on broad, long-term aspects of investing. Behavioral biases are more likely to occur in more narrowly focused trading tasks.

Finally, we find that the results of the final rebalancing task seem to influence the hormone level of the subjects. The higher the total return achieved, the greater the change in testosterone. We mention studies that report a link between the psychology, sentiment, or physiology of investors and their subsequent trading choices. However, few studies report evidence that investment decisions impact the psychology, sentiment, or physiology of investors. However, this link is important in many models of the stock market that include a feedback process. For example, Shiller (2002) argues that speculative bubbles form because of a feedback loop in which optimistic investors bid up prices. The increased prices subsequently cause investors to be more optimistic and to buy more stocks, perpetuating the cycle. Our evidence is consistent with the hypothesis that "winning" in the stock market increases testosterone, which in turn can increase the investment risk taken by the investor.

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Table 1 Subject Sample Statistics

This table displays the subject sample statistics. Panel A shows the gender breakdown of the subjects and their ethnicity distribution. Panel B shows the age and number of years of investment experience of the subjects.

Panel A: Gender and Ethnicity

Total	Male	Female
39	27	12

Asian	Black	Hispanic	Caucasian
12	3	17	7

Panel B: Age and Investment Experience

	Mean	Median	Std Dev
Age	27.4	25.3	6.4
Investment Experience	0.68	0.0	1.5

Table 2 Sample Statistics for First Portfolio Allocation Task

This table displays the sample statistics of the first asset allocation decision task. Panel A shows the expected annual return and volatility of the six assets available (HOME, GROW, BOND, MINE, MMKT, CASH). It also shows the average portfolio allocation to each asset. Panel B shows the frequency with which the given number of assets were selected for each portfolio. Panel C reveals the average expected return selected by the subjects' portfolios. Average Volatility for each portfolio is the sum of the fraction allocated to each asset, multiplied by the volatility of each asset. The average (standard deviation) of this statistic is reported for all the portfolios. The Sum of Squared Allocations is the sum of the squared fraction allocated to each asset. The average and standard deviation of the portfolios are reported.

Panel A: Asset Allocation Choices for First Portfolio Allocation Task

	HOME	**GROW**	**BOND**	**MINE**	**MMKT**	**CASH**
Expected Return	8.5%	13%	4.5%	6.0%	2.0%	0%
(Volatility)	(18%)	(30%)	(8%)	(16%)	(1%)	(0%)
DIV1	21.9%	24.0%	12.8%	13.8%	7.0%	20.5%
(Standard Dev.)	(16.3%)	(14.1%)	(9.5%)	(11.5%)	(8.7%)	(29.6%)

Panel B: Asset Allocation Frequency for the Number of Assets Allocated

# of Assets in Portfolio	**1**	**2**	**3**	**4**	**5**	**6**
# of Subjects Selecting	0	5	2	5	25	2

Panel C: Return and Risk Choices

Expected Return	**Average Volatility**	**Sum of Squared Allocations**
6.53%	14.45%	0.347
(2.54%)	(5.74%)	(0.178)

Table 3 Testosterone and Stress Influences on Diversification Choices

This table shows OLS regressions of testosterone and cortisol levels on different measures of risk and return choices for the first diversification decision. Models include the linear and squared level of testosterone and cortisol, as well as an indicator variable to denote female participants. Panel A reports the regression results for five models where expected return is the dependent variable. Results for regressions are shown for the average volatility of the allocations (Panel B), the number of assets selected in the portfolio (Panel C), and the sum of the squared asset weights (Panel D). Significance is displayed at the 10% (*) and 5% (**) levels.

Panel A: Expected Return

Intercept	Sal-T	Sal-T^2	Sal-C	Sal-C^2	Female	R^2
6.52***	-0.759*					0.09
6.88***	-0.738*	-0.025			-0.99	0.13
6.51***			-0.693*			0.08
6.77***			-0.799	0.085	-1.02	0.11
6.51***	-0.560		-0.423			0.11

Panel B: Average Volatility

Intercept	Sal-T	Sal-T^2	Sal-C	Sal-C^2	Female	R^2
0.144***	-0.017*					0.09
0.152***	-0.016*	-0.004			-0.023	0.13
0.144***			-0.015*			0.07
0.150***			-0.018	0.006	-0.024	0.11
0.144***	-0.012		-0.009			0.11

Panel C: Number of Assets in Portfolio

Intercept	Sal-T	Sal-T^2	Sal-C	Sal-C^2	Female	R^2
4.43***	-0.154					0.02
4.53***	-0.121	-0.066			-0.074	0.03
4.43***			-0.301*			0.07
4.47***			-0.281	-0.016	-0.076	0.08
4.43***	-0.016		-0.294			0.07

Panel D: Sum of Squared Allocations

Intercept	Sal-T	Sal-T^2	Sal-C	Sal-C^2	Female	R^2
0.348***	0.041					0.06
0.337***	0.034	0.014			-0.010	0.06
0.348***			0.061**			0.12
0.332***			0.036	0.020	-0.009	0.14
0.348***	0.016		0.053*			0.12

Table 4 Sample Statistics for Second Portfolio Allocation Task

This table displays the sample statistics of the second asset allocation decision task. Panel A shows the expected annual return and volatility of the six assets available, which are the same as in Table 3. It also shows the annualized actual return realized from the first portfolio allocation task. The new average portfolio allocation to each asset is shown with a paired means test with the allocation from the first task. Panel B shows the frequency with which the given number of assets were selected for each portfolio. Panel C displays the average expected return selected by the subjects' portfolios. Average Volatility for each portfolio is the sum of the fraction allocated to each asset multiplied by the volatility of each asset. The average (standard deviation) of this statistic is reported for all the portfolios. The Sum of Squared Allocations is the sum of the squared fraction allocated to each asset. The average and standard deviation of the portfolios are reported. The results of the paired difference in means test is also shown for each variable. Significance is displayed at the 10% (*), 5% (**) and 1% (***) levels.

Panel A: Asset Allocation Choices for Second Portfolio Allocation Task

	HOME	**GROW**	**BOND**	**MINE**	**MMKT**	**CASH**
Expected Return (Volatility)	8.5% (18%)	13.0% (30%)	4.5% (8%)	6.0% (16%)	2.0% (1%)	0.0% (0%)
Realized Return from PORT1	7.86%	17.28%	1.96%	4.43%	2.03%	0.00%
PORT2 Allocation (Standard Dev.)	25.1% (15.7%)	28.0% (13.6%)	15.6% (12.0%)	16.8% (11.0%)	7.3% (9.1%)	7.3% (20.1%)
Different from PORT1	*	*	*	*		***

Panel B: Asset Allocation Frequency for the Number of Assets Allocated

# of Assets in Portfolio	**1**	**2**	**3**	**4**	**5**	**6**
# of Subjects Selecting	0	2	3	6	25	3

Panel C: Return and Risk Choices

	Expected Return	**Average Volatility**	**Sum of Squared Allocations**
PORT2 Portfolios	7.62% (2.10%)	16.91% (4.83%)	0.319 (0.112)
Different from PORT1	***	***	*

Table 5 Testosterone and Stress Influences on Changes in Asset Allocation Choices
This table shows regressions of testosterone and cortisol levels on the changes in risk and return compared to the first allocation decision. Models include the linear and squared level of testosterone and cortisol, as well as an indicator variable to denote female participants. Panel A reports the regression results for five models where the change in expected return is the dependent variable. Changes are measured as the value of the measure in the second decision minus value from the first decision. Results for regressions are also shown for the change in the average volatility of the allocations (Panel B), change in the sum of the squared asset weights (Panel C), and the change in the allocation to the GROW Asset (Panel D). Significance is displayed at the 10% (*), 5% (**) and 1% (***) levels.

Panel A: Change in Expected Return

Intercept	Sal-T	Sal-T^2	Sal-C	Sal-C^2	Female	R^2
1.10***	0.606*					0.09
0.63	0.526	0.144			0.99	0.14
1.11***			0.728**			0.12
0.83*			0.794*	-0.054	1.00	0.17
1.11***	0.341		0.564			0.14

Panel B: Change in Average Volatility

Intercept	Sal-T	Sal-T^2	Sal-C	Sal-C^2	Female	R^2
0.025***	0.014*					0.09
0.015	0.013	0.002			0.021	0.14
0.025***			0.016**			0.12
0.020*			0.020*	-0.003	0.022	0.17
0.140***	0.008		0.012			0.14

Panel C: Change in the Sum of Squared Allocations

Intercept	Sal-T	Sal-T^2	Sal-C	Sal-C^2	Female	R^2
-0.029	-0.050**					0.15
0.018	-0.033	-0.034**			-0.037	0.25
-0.029			-0.058***			0.19
0.018			-0.016	-0.034**	-0.037	0.34
-0.029	-0.030		-0.044*			0.23

Panel D: Change in the Allocation to the GROW Asset

Intercept	Sal-T	Sal-T^2	Sal-C	Sal-C^2	Female	R^2
0.040	0.031					0.04
0.026	0.023	0.017			-0.010	0.06
0.040			0.042*			0.08
0.046			0.045	-0.002	-0.010	0.08
0.040	0.015		0.035			0.08

Table 6 Testosterone and Stress Influences on Trading

Testosterone and cortisol levels are examined in relation to trading decisions in the rebalancing exercise. Panel A reports the OLS regression for Excess Expected Return. Excess Expected Return is the expected return selected minus the return needed to meet the final accumulation goal. Panel B reports the regression for the asset allocation change for assets that lost money during the previous five years. Panel C reports the regression results for the allocation change to the asset with the highest return from the previous five-year period. Significance is displayed at the 10% (*), 5% (**) and 1% (***) levels.

Panel A: Excess Expected Return

Intercept	**Sal-T**	**Sal-T^2**	**Sal-C**	**Sal-C^2**	**Female**	**REBAL1**	**REBAL2**	**REBAL3**	**R^2**
0.026***	0.007*	-0.005	-0.006	-0.000	-0.011	-0.001	0.012	-0.021**	0.14
(0.001)	(0.079)	(0.109)	(0.195)	(0.994)	(0.115)	(0.930)	(0.178)	(0.023)	

N=156

Panel B: Buy/Sell Losers

Intercept	**Sal-T**	**Sal-T^2**	**Sal-C**	**Sal-C^2**	**Female**	**BOND**	**R^2**
0.90***	-0.027	0.004	0.045*	-0.010	-0.039	0.001	0.07
(0.002)	(0.190)	(0.797)	(0.079)	(0.427)	(0.235)	(0.976)	

N=76

Panel C: Buy/Sell Winners

Intercept	**Sal-T**	**Sal-T^2**	**Sal-C**	**Sal-C^2**	**Female**	**REBAL1**	**REBAL2**	**R^2**
-0.097**	-0.007	-0.009	-0.030	0.014	0.010	-0.151***	0.013	0.15
(0.013)	(0.756)	(0.618)	(0.306)	(0.372)	(0.790)	(0.001)	(0.774)	

N=117

Table 7 Impact of Investing on Testosterone and Stress

This table reports the impact that trading has on the hormone levels of the subjects. The subjects' testosterone and cortisol levels were measured after the rebalancing exercise and compared to the pre-event measurement. The change in testosterone (Panel A) and change in cortisol (Panel B) are regressed on final rebalancing results. Specifically, the final rebalancing results are measured as the total return earned over the 20-year simulation and a dummy variable stating whether the financial goal was met or not. Significance is displayed at the 10% (*) and 5% (**) levels. N=39.

Panel A: Change in Testosterone

Intercept	Total Return	Met Goal	R^2
-0.779**	0.561**		0.14
(0.028)	(0.018)		
-0.094		0.533	0.06
(0.530)		(0.136)	
-0.849*	0.629*	-0.137	0.14
(0.054)	(0.068)	(0.781)	

Panel: B Change in Stress

Intercept	Total Return	Met Goal	R^2
-0.609	0.428		0.05
(0.196)	(0.173)		
-0.144		0.731	0.07
(0.453)		(0.112)	
-0.317	0.144	0.578	0.07
(0.583)	(0.751)	(0.387)	

Figure 1 Average Returns during Each Decision Point
This graph shows the average realized portfolio annual return across the 39 portfolios for the five-year simulation periods before each of the three rebalancing decision points. It also shows the average annualized return needed for the balance of the 20-year period to achieve the portfolio value goal. Lastly, the graph shows the average expected return selected by the participants.