

Endogenous steroids and financial risk taking on a London trading floor

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Little is known about the role of the endocrine system in financial risk taking. Here, we report the findings of a study in which we sampled, under real working conditions, endogenous steroids from a group of male traders in the City of London. We found that a trader's morning testosterone level predicts his day's profitability. We also found that a trader's cortisol rises with both the variance of his trading results and the volatility of the market. Our results suggest that higher testosterone may contribute to economic return, whereas cortisol is increased by risk. Our results point to a further possibility: testosterone and cortisol are known to have cognitive and behavioral effects, so if the acutely elevated steroids we observed were to persist or increase as volatility rises, they may shift risk preferences and even affect a trader's ability to engage in rational choice.

cortisol | testosterone | reward | uncertainty | neuroeconomics

Testosterone, produced by the Leydig cells of the testes and in smaller amounts by the adrenal cortex, mediates sexual behavior and competitive encounters. It rises, for example, in athletes preparing for a competition and rises even further in the winning athlete, while falling in the losing one (1, 2). This androgenic priming of the winner can increase confidence and risk taking and improve chances of winning yet again, leading to a positive-feedback loop termed the "winner effect" (3, 4). Cortisol, produced by the adrenal cortex, plays a central role in the physiological and behavioral response to a physical challenge or psychological stressor. Cortisol is particularly sensitive to situations of uncontrollability, novelty, and uncertainty (5). Its wide-ranging effects include dampening the immune system; stimulating glucose metabolism; and altering mood, memory, and behavioral response to threatening circumstances (6–8). Because testosterone has been found to play a role in winning and losing, and cortisol has been found to play a role in responding to stress and uncertainty, we developed the hypothesis that these steroids would respond to financial risk taking. Specifically, we predicted that testosterone would rise on days when traders made an above-average gain in the markets, and cortisol would rise on days when traders were stressed by an above-average loss. Our data confirmed the first prediction but suggested that cortisol responds more to uncertainty of return than to loss.

In designing our protocol, we assumed that traders would experience a large endocrine reaction only if the risks they were taking and the consequent profit and loss were large enough to matter to them; if, that is, the trading would meaningfully affect their income, reputation, or, in the worst case, chances of being fired. We therefore decided to conduct the study on a real trading floor rather than under laboratory conditions and to sample steroids while traders did their normal jobs (9). With permission from the managers of a midsized trading floor (≈ 260 traders, of which 4 were female) in the City of London, we recruited 17 male traders to participate in the study.

This trading floor was typical of most in terms of its physical setup; the assets traded; and the age, sex, and income distribu-

tion of the traders. The traders, in the normal course of a working day, sit in front of a bank of computer screens displaying live prices of currency, commodity, bond, and stock index futures (Fig. 1). Their trading stations also include live news-feeds, a risk-management system, and an intercom, over which a resident economist gives a commentary on the economic statistics being released around the globe. Traders on our floor could trade a wide range of assets, but most had been assigned or had chosen one or two, and all had their largest exposure to the German markets and in particular to German interest rate futures. The nominal size of their individual trades ranged, depending on the trader's level of experience, from £100,000 to £500,000,000. Traders could keep their positions overnight, but most closed out their trades by the end of the day, so they were at risk only during London trading hours. The traders ranged in age from 18 to 38, with a mean of 27.6 years. Annual income of traders on this floor, after broker commissions and profit sharing with the employing firm, ranged from £12,000 to over £5,000,000.

We followed these 17 traders for 8 consecutive business days, taking saliva samples twice per day, at 11:00 a.m. and 4:00 p.m. (10), times that fell before and after the bulk of the day's trading. At each sampling time, traders recorded their profit and loss (P&L), a number displayed live throughout the day on their computerized risk-management system. At the end of each day, the traders filled out a short questionnaire asking, among other things, about food and drinks recently consumed or medication taken. The questionnaire also asked whether the traders had received any important news from outside work. This question, like the others, was designed to find out whether anything other than trading had affected the subject's endocrine system that day. No subject consumed anything during the study that would interfere with his endocrine system, and none received any important personal news.

We tried to time the study to coincide with a period of market volatility. However, large market moves are random events, so this timing is difficult. Nonetheless, volatility is driven by new information, and we do know when economic information is released: governments and private survey firms around the world release economic statistics according to a fixed calendar. The U.S. calendar, in particular, is closely watched, and most foreign markets pay more attention to U.S. economic numbers than to their own (11). For that reason, we conducted the study during a period that led up to and included the most important U.S. economic releases, foremost of which were the Institute of Supply Management Manufacturing Index and the Employment Report (Table 1). The statistics are released at set times during the day, all of which occur between 8:30 and 10:00 a.m. New

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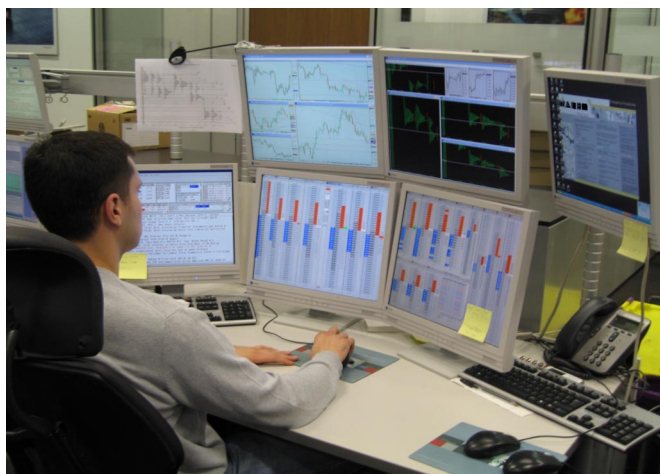


Fig. 1. Trading desk.

York time (1:30 and 3:00 p.m. London time). Our sampling times bracketed these economic releases and, it was hoped, the times of greatest volatility.

Results

According to our prediction, a trader's testosterone should rise on days when he makes more money than his daily average. For average daily P&L, we used data provided by the bank on each trader's trading history. Based on these data, we partitioned each trader's days into those when he made more money than his daily average from the past month and those when he either made less than this amount or lost money. We found that daily testosterone (i.e., mean of 11:00 a.m. and 4:00 p.m. samples) was significantly higher on days when traders made more than their 1-month daily average than on other days (paired t test; $t = 2.8$, $P = 0.012$, two-tailed, $n = 17$). There was no correlation with the following days' P&L (data not shown). We also analyzed each time point using generalized estimating equations (GEE) (see *Materials and Methods*). Using GEE, we found a significant correlation between 4:00 p.m. P&L and both 11:00 a.m. testosterone (95% CI 0.008–0.021; $P = 0.015$) and 4:00 p.m. testosterone (95% CI 0.003–0.014; $P = 0.008$).

We next looked into the direction of the relationship between testosterone and P&L. To do so, we analyzed a trader's 11:00 a.m. testosterone and the P&L he made after this sampling time. We divided a trader's days into those when his 11:00 a.m. testosterone was above his median level during the study, and those when it was below. This division produced two sets of days with a 25.1%

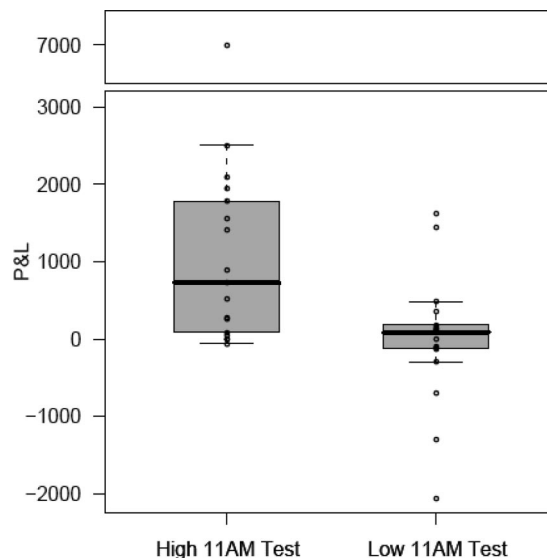


Fig. 2. Testosterone and economic return. Boxplot showing average profit and loss (P&L, y axis, £ sterling) made between 11:00 a.m. and 4:00 p.m. on days when subjects had 11:00 a.m. testosterone above (High) and below (Low) their median during the study. Individual data points are shown. Fourteen out of 17 subjects had higher P&L on high testosterone days than on low; the remaining subjects had negligible differences.

difference in morning testosterone. On days of higher 11:00 a.m. testosterone, traders made a P&L for the rest of the day that was significantly greater than on lower testosterone days (paired t test; $t = 3.03$, $P = 0.008$, two-tailed, $n = 17$; Fig. 2). One P&L data point was an outlier, so we also used a nonparametric test, and this too showed a highly significant difference in P&L (Wilcoxon signed-rank test, $W = 141$, $P = 0.001$, $n = 17$). Furthermore, the difference in mean P&L between these two sets of days was large (Cohen's $d = 0.97$). Because the days of high 11 a.m. testosterone were different for each trader, thereby ruling out any general market effects on both testosterone and P&L, our results suggest that high morning testosterone predicts greater profitability for the rest of that day.

To test our prediction concerning cortisol and trading losses, we divided a trader's days into those when he lost and those when he made money, only in this case we used the negative value of the traders' average daily gain over the past month as a measure of an above-average daily loss. There was, however, no significant difference in cortisol levels between these days (paired t test; $t = 0.12$; $P = 0.9$, two-tailed, $n = 14$, because three subjects had no large losses). We also divided the days into those when a trader lost

Table 1. Calendar of U.S. economic releases during the study

Week	Monday	Tuesday	Wednesday	Thursday	Friday
1		Home sales (3:00 p.m.)	Durable goods (1:30 p.m.)	Unemployment claims GDP (revised) (1:30 p.m.)	Personal income (1:30 p.m.)
2	Bank holiday Referendum results	Chicago PMI (3:00 p.m.)	ISM (3:00 p.m.)	Unemployment claims (1:30 p.m.)	Early close (7:00 p.m.) Employment report (1:30 p.m.)

The week from Chicago Purchasing Managers Index (Chicago PMI) to the Employment Report includes the most important U.S. economic numbers and is often the biggest week of the month for traders in terms of volatility and P&L (see Fig. 4). Home sales, existing homes sales; durable goods, sales of goods that last >2 years; unemployment claims, weekly claims for unemployment insurance benefits; GDP, gross domestic product; early close, U.S. markets closed midafternoon on Friday before a long weekend; referendum results, results of Sunday's French referendum on the European Union constitution; ISM, Institute of Supply Management Manufacturing Index; and employment report, unemployment rate plus monthly change in nonfarm payrolls. Times given in parentheses are Greenwich Mean Time. Sampling days are in bold.

Table 2. Traders' summary statistics

	Age	Years trading	Testosterone	Cortisol	Approximate annual income, first-year traders not included, £
			Average of a.m. plus p.m., pg/ml	Average of a.m. plus p.m., pg/ml	
Mean	27.5	2.6	114	1,697	164,000
Std	5.6	1.9	24	749	135,000
Range	19/38	9 mo/6 yrs	67/184	617/4,322	21,770/443,340

suggest there may be a biological substrate for the options market, a market of enormous size and influence in the global economy.[†]

Discussion

We found a significant relationship between testosterone and financial return and between cortisol and financial uncertainty, the latter being measured by the variance of economic return and the expected variance of the market. The protocol developed to test these relationships had the advantage of using only objective measures: steroid assays, option prices, and daily and historic P&L. However, it had the drawback of sampling over only 8 days. It had the further drawback of being conducted during what turned out to be a period of low volatility. Realized volatility on the Bund contract during the 2 weeks of the study was 3.45%, whereas the average for the previous 5 years was 4.75% [with a maximum of 11.76% reached in the late autumn of 2001, after September 11, 2001 (9/11), and a minimum of 1.73% reached earlier that same year]. Such low volatility makes it difficult to assess the potential size of the hormonal effects stemming from the markets.[‡]

However, if acutely raised steroids were to persist for several weeks or even increase as volatility rises, they might have cognitive and behavioral consequences, specifically by shifting risk preferences or disturbing the neural basis for rational choice. Research into how this may happen is in its infancy, but recent work in neuroscience and economics has shown how various brain regions, such as the amygdala (13–15), the anterior insula (16), and the nucleus accumbens (16, 17), encode decisions and behaviors that deviate from rational choice. It has been suggested that, if these brain regions are overactivated, then investors will display the irrational behavior often observed in real markets (16). It is not often asked how this may happen, but one possibility is that the endocrine system acts as a relay between market events and the neural systems involved in economic decision making (18, 19). In particular, testosterone and cortisol have receptors throughout the brain regions identified in neuroeconomic research as contributing to irrational financial decisions, so these steroids, as they fluctuate with risk and return, may alter a trader's ability to make optimal decisions.

When traders in our study experienced acutely raised testosterone, for example, they made higher profits, perhaps because testosterone has been found, in both animal and human studies,

to increase search persistence (20), appetite for risk (21), and fearlessness in the face of novelty (22, 23), qualities that would augment the performance of any trader who had a positive expected return. However, if testosterone continued to rise or became chronically elevated, it could begin to have the opposite effect on P&L and survival (24), because testosterone has also been found to lead to impulsivity and sensation seeking (25), to harmful risk taking (21), and, among users of anabolic steroids, to euphoria and mania (26). In one study, testosterone was administered to a group of subjects playing the Iowa Gambling Task, and it led to irrational risk–reward tradeoffs, causing the subjects to prefer the high-variance negative expected-return decks of cards to the low-variance positive expected-return decks (27, 28). It has also been found that testosterone and its metabolite, 3 α -androstenediol, have rewarding and addictive properties, largely because they increase dopamine release in the shell of the nucleus accumbens (29, 30), a brain region found to be stimulated in anticipation of irrational risk seeking (16). Testosterone may therefore underlie a financial variant of the “winner effect,” in which a previous win in the markets leads to androgenic priming and increased (and eventually irrational) risk taking in the next round of trading. This effect, even if confined to a small number of people, could cause financial markets to deviate from the predictions of rational choice theory (31).

Rising cortisol could also affect a trader's risk preferences but in the opposite direction to testosterone. During our study, traders experienced acutely raised cortisol in anticipation of higher volatility and the increased chances of making money that higher volatility brings. Cortisol (along with other glucocorticoids such as corticosterone) is known to have powerful cognitive and emotional effects. These effects depend on the amount of steroid reaching the brain, the duration of the exposure, and the timing of the exposure relative to the event that is to be learned or remembered (32). If exposure is acute, glucocorticoids can be euphorogenic, increasing motivation and promoting focused attention. They can also aid the consolidation and retrieval of important memories (6, 7). However, if elevated glucocorticoids persist, their effects can be debilitating. During times of chronic stress, glucocorticoids, acting through the amygdala and hippocampus, promote a selective attention to mostly negative precedents (6); stimulate corticotrophin-releasing hormone (CRH) gene expression in the central nucleus of the amygdala and consequent feelings of anxiety (33); and produce a tendency to find threat and risk where none exist (34). Together, these effects would tend to decrease a trader's risk taking. A situation of chronically elevated cortisol might occur if financial market volatility were to rise for an extended period, something that normally happens when the economy receives an unwelcome shock or enters a depression (35).

Cortisol is likely, therefore, to rise in a market crash and, by increasing risk aversion, to exaggerate the market's downward movement. Testosterone, on the other hand, is likely to rise in a bubble and, by increasing risk taking, to exaggerate the market's

[†]The Bank for International Settlements estimates that the market in equity, currency, commodity, and interest rate options, both over-the-counter and exchange-traded, now represents a notional amount of over \$90 trillion, and even that number does not include markets in which implied volatility has a large effect on prices, such as the swap, mortgage, and insurance markets, or markets for new instruments, such as weather derivatives [Bank for International Settlements (2006) *Semiannual OTC Derivatives Statistics at End December 2005* (www.bis.org/statistics/derstats.htm)].

[‡]A couple of individual cases are worth mentioning. One trader who had a P&L several times his daily average one day level saw his mean testosterone rise 56% above his average for the other days. Another trader enjoyed a 6-day winning streak, averaging about twice his historic daily P&L, and in the course of this winning streak his mean daily testosterone levels rose 74%. Despite the high levels of these individual testosterone readings, none of them constituted an outlier. Traders' cortisol, as mentioned above, had an even higher day-to-day variance than testosterone.

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