

Endogenous steroids and financial risk taking on a London trading floor

J. M. Coates*^{†‡} and J. Herbert*[§]

*Department of Physiology, Development and Neuroscience, University of Cambridge, Cambridge CB2 3DY, United Kingdom; [†]Judge Business School, University of Cambridge, Cambridge CB2 1AG, United Kingdom; and [§]Cambridge Center for Brain Repair, University of Cambridge, Cambridge CB2 0PY, United Kingdom

Edited by Bruce S. McEwen, The Rockefeller University, New York, NY, and approved November 6, 2007 (received for review May 1, 2007)

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

Author contributions: J.M.C. and J.H. designed research; J.M.C. performed research; J.M.C. and J.H. analyzed data; and J.M.C. and J.H. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

[†]To whom correspondence may be addressed. E-mail: jmc98@cam.ac.uk or jh24@cam.ac.uk.

© 2008 by The National Academy of Sciences of the USA



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%

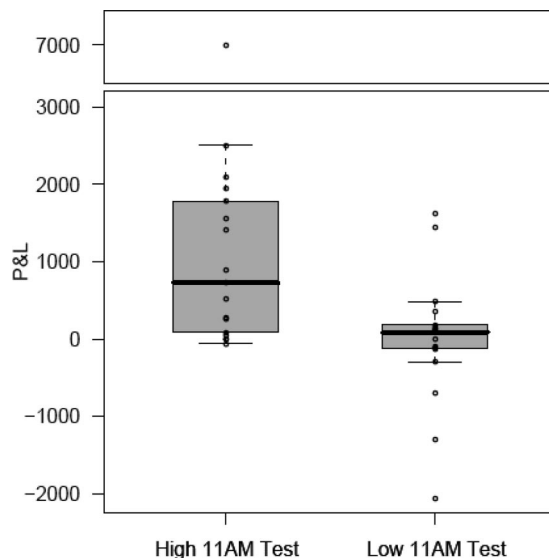


Fig. 2. Testosterone and economic return. Boxplot showing average profit and loss (P&L, y axis, £ sterling) made between 11:00 a.m. and 4:00 p.m. on days when subjects had 11:00 a.m. testosterone above (High) and below (Low) their median during the study. Individual data points are shown. Fourteen out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

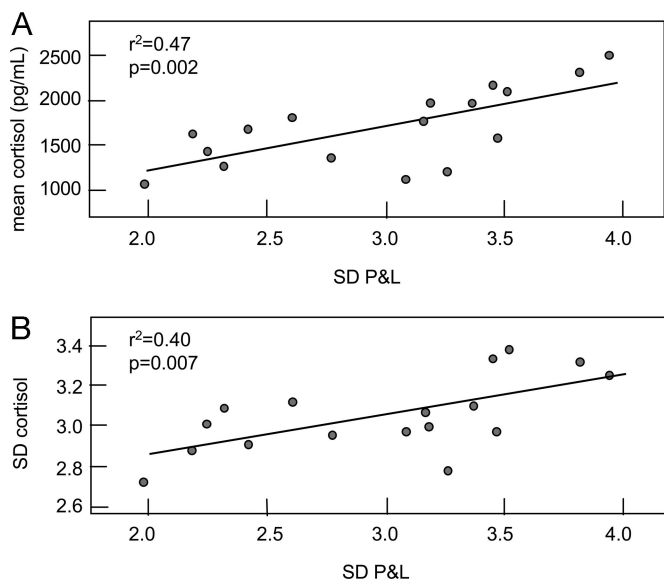


Fig. 3. Cortisol and the variance of economic return. (A) Plot of mean cortisol (pg/ml) during the study for each trader correlated against the standard deviation of his profit and loss (P&L, logs). (B) Standard deviation of each trader's cortisol correlated against the standard deviation of his P&L (logs).

money, no matter how much, and those when he made money or was flat but found no significant difference in cortisol levels (paired t test; $t = 0.21$; $P = 0.83$, two-tailed, $n = 16$). Last, we looked to see whether cortisol responded to above-average daily gains, as we did with testosterone, but once again found no significant difference between the two sets of days (paired t test; $t = 0.05$; $P = 0.96$, two-tailed, $n = 17$). These findings were confirmed by GEE analysis. We thus found no relationship between the level of cortisol and the level of P&L. Such a relationship might well exist; in a larger study, we might observe, for example, altered cortisol levels in a trader who had fallen into a sustained losing streak, but in our study, we did not observe anyone in that unfortunate state.

We therefore looked to see if cortisol was responding to risk, as measured by the variance of a trader's returns. We took an average over the study of each trader's daily cortisol and correlated this average with the standard deviation of his P&L: we found that the more volatile a trader's P&L, the higher were both his average daily cortisol levels ($r^2 = 0.48$, $P = 0.004$, $n = 17$; Fig. 3A) and the standard deviation of his daily cortisol levels ($r^2 = 0.40$, $P = 0.007$; $n = 17$; Fig. 3B). These results suggest that individual levels of cortisol relate not to the rate of economic return, as does testosterone, but to the variance of return.

We suspected that, in addition to variance of return, something else related to work or the markets was perturbing the traders' hypothalamus-pituitary-adrenal (HPA) axes, because their cortisol levels were unusually volatile. Instead of falling over the course of the day, cortisol rose in 38% of our subjects' days, with some levels rising as much as 500% from morning to afternoon. Mean daily cortisol levels also experienced large variation, in some subjects up to 400% between days. Cortisol can experience changes of these magnitudes in situations other than distressing ones like losing money; it can rise in expectation of challenge and sustained effort, and it does so to promote anticipatory arousal and focused attention (6). An HPA reaction of this sort can occur when people are faced with situations of novelty and uncertainty (5). Traders face varying levels of novelty and uncertainty every day, so this feature of their jobs may help explain the high variance of their cortisol levels.

How can we measure the expected challenge or uncertainty faced by traders? Conveniently, there is a market for hedging uncertainty,

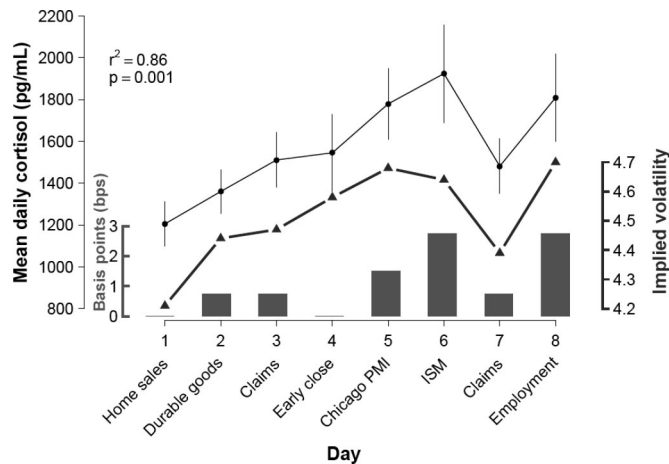


Fig. 4. Group cortisol plotted against implied volatility of German Bunds. Implied volatility in most bond markets follows the calendar of U.S. economic statistics, rising during the week of Chicago Purchasing Managers Index (PMI), peaking on or just before the Employment Report, and dropping after the information contained in these numbers has reduced uncertainty over the state of the economy. The upper line is the daily cortisol level averaged from the group of traders (left axis, pg/ml; mean \pm SEM, $n = 11$). The lower line is the implied volatility from German Bund (bond future) options with ≈ 1 month to expiration [right axis; Annualized standard deviation of the natural logs of daily price returns. Friday options (days 4 and 8) repriced to Sunday to eliminate the weekend effect. Bloomberg data]. Shaded bars display the importance of each economic release. The bars represent regression-derived day weights, i.e., the extra variance in Bund yields expected on that day due to the release of the U.S. economic statistic [lower left axis; basis points in yield change (12)]. The bars are for illustrative purposes only and do not enter into the statistical analysis. Implied volatility on day 5 was higher than expected, given the relative importance of the Chicago PMI, because the German market was surprised by the result of the French referendum.

with objective measures, i.e., prices, that can be read off a screen. This is the market for options and derivatives. An option is a tradable contract that gives the owner the right to either buy or sell an asset at a stated price during a fixed period. To value these contracts, a trader requires an estimate of the future variance of the price of the underlying asset. For this reason, the options market is, in effect, a market for expected volatility, one that measures uncertainty. When markets are shocked by an unanticipated event (the fall of the Berlin Wall, the Asian financial crisis, war in the Middle East), volatility increases. When markets are uncertain of the outcome of an important scheduled event, like an election, a referendum, or the release of an economic statistic, expected volatility also increases. Therefore, the implied volatility, i.e., the estimate of future variance implied by an option's price, is a sensitive barometer of the market's collective uncertainty and expectation of an impending market move.

Consequently, we looked to see whether cortisol rose with increasing levels of uncertainty, as measured by implied volatility. Because all traders had their largest exposure to the German markets, we used implied volatility from options on the Bund (10-year bond futures) with ≈ 1 month to expiration as a proxy for the uncertainty affecting their core positions. We found that daily group average cortisol levels did, in fact, correlate strongly with Bund implied volatility ($r^2 = 0.86$, $F = 38.1$, $P = 0.001$, $n = 11$; Fig. 4). Testosterone, however, did not show a significant correlation with implied volatility ($r^2 = 0.36$, $F = 3.1$, $P = 0.13$). Cortisol was likely responding to uncertainty rather than the other way around, because the calendar of economic releases and the relative importance of the economic statistics that create the uncertainty are independent of hormones. Last, the relationship between cortisol and volatility was strong enough to

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.

Table 3. Number of subjects trading each security

Security	Euribor	Schatz	Bobl	Bund	Dax	Eurostox	Euro/\$	U.S. note	Gilt
Primary trading security	2	1	2	8	3	1			
Secondary trading securities	1		2	8	2	3	3	4	1
Total	3	1	4	16	5	4	3	4	1

upward movement. These steroid feedback loops may help explain why people caught up in bubbles and crashes often find it difficult to make rational choices.**

Materials and Methods

Subjects. To recruit our subjects, we distributed around the trading floor of the hosting firm a one-page introduction to the study. It stated we were studying the ways in which the body and in particular the endocrine system respond to stress and volatility in the financial markets; it also described our protocol. Interested subjects were invited to a 1-hour talk at which we explained the study and protocol in greater detail. Potential subjects were told that, upon completion of the study, they would receive the results of their steroid assays and a brief account of our findings; they were not offered payment. They were also told that the results of their steroid assays and the records of their daily P&L would be confidential: these data would be coded, and only a senior laboratory technician at University of Cambridge would be able to match their names to the codes. Eighteen traders agreed to participate, although one subject left the firm before the study began. At the end of the study, traders were sent a one-page letter containing the results of their steroid assays, the average assay results for the other traders, and a brief description of our initial findings. All subjects signed an informed consent form. The study was approved by the ethics committee of the School of Biological Sciences at the University of Cambridge.

Procedure. Subjects filled out an initial questionnaire asking about their general health. They were asked in particular about any habits or medications that might affect their steroid levels. No subject smoked or was a vegetarian; no subject drank more than one or two cups of tea or coffee per day, and the few that did so consumed moderate amounts of caffeine regularly, a consumption pattern that has been found to leave cortisol levels largely unaffected (37). No subject used an inhaler; took synthetic steroids or medication for pain, stress, or depression; and none had gingivitis, a condition that can introduce blood into saliva.

The questionnaire also asked about the trader's trading history, questions such as how long he had traded, what was his best and worst single day's P&L, and what was his estimated average 1-day P&L. Seven of the subjects were in their first year of trading, three in their second, and seven were more experienced (Table 2).

Fixed sampling times were used because steroids follow a diurnal cycle, peaking in the morning and declining over the course of the day. At 11:00 a.m. and 4:00 p.m., subjects deposited 3 ml of saliva into a polystyrene vial. To ensure compliance and consistency in sampling time across traders, one of the authors provided the sampling vials at 15 min before the hour and picked them up between 15 and 30 min after the hour. Nine subjects needed to chew a piece of sugar-free gum to stimulate saliva production, but they did so for every sample. Samples were frozen at -20°C and later assayed for testosterone and cortisol. Testosterone was assayed in saliva duplicates by using a validated RIA with ether extraction. Sensitivity was 0.012 ng/ml, intraassay coefficient of variation (CV) = 3.9% and interassay CV = 3.7%. Cortisol was assayed in saliva duplicates without extraction by using a validated ELISA; sensitivity was 0.1 ng/ml; intraassay CV = 3.7%, and interassay CV = 8.4%.

We performed 1 day of trial sampling to familiarize the traders with the procedure. Then, for the study, we sampled over another 8 business days (38). P&Ls from 11:00 a.m. and 4:00 p.m. were recorded from traders' risk-management systems. These systems provide the traders with live P&L figures identical to those viewed by the back office. The P&Ls recorded by the traders during the study were therefore free of reporting bias. In addition to these intraday P&Ls, we also received from the brokerage firm

official end-of-day P&L figures for each trader, fixed when the traders have stopped trading.

Analysis. Steroids were sampled over an 8-day period. However, for the purposes of analysis, the 8 days were divided into two groups: high/low P&L, high/low steroid levels, etc. We therefore used within-subject *t* tests for initial analyses of the relationship between salivary steroid levels and daily P&L. Steroid measures were log-transformed where required. Statistical analyses were conducted by using SPSS, Ver. 11.5 (SPSS).

The data set for testosterone and cortisol levels was also treated as panel data, with days nested within individuals. Analyses were performed by using GEE (39). The dependent variable was the daily measure (a continuous variable) and the trader's profit or loss (a time-varying covariate, different for each day). The other covariate was the trader's experience (number of years trading). GEE extends the generalized linear model to allow for correlated observations (e.g., in a longitudinal study). It characterizes the marginal expectation (the average response for observations sharing the same covariates) as a function of covariates. Here, the principal covariate of interest is the gain or loss covariate for each day. The GEE method accounts for the correlation between observations in generalized linear regression models by use of empirical (sandwich/robust) variance estimators and posits a model for the working correlation matrix. Here, we used the exchangeable correlation structure. All GEE models were implemented by using *xtee* commands in Stata 9 with linear risk function for continuous outcomes (daily hormone levels).

Trading and Implied Volatility. All subjects traded one main security; many traders also occasionally traded one or two other securities (Table 3). For 13 traders, the main security traded was a European fixed income future, either Euribor (3-month Euro bank deposits), Schatz (2-year German bond futures), Bobl (5-year German bond futures), or Bunds (10-year German bond futures). Because all of these contracts have as an underlying asset a European, and in particular a German, interest rate future, they respond to the same economic statistics (12). For the other four traders, the main asset traded was the Dax (German stock index futures) or Eurostox (European Equity Index), although three of them also traded Bunds. The secondary securities traded included, in order of importance, U.S. Treasury Notes, \$/Euro currency futures, and Gilts (U.K. Treasury Futures). Because most traders traded either Bunds or a German fixed-income future, we used Bund-implied volatility as a proxy for expected volatility in their core positions. Cortisol levels were averaged from 11 traders, because two traders missed an afternoon sample, and four others took days off. For plotting day weights, we used the 7-year German swap rate as a proxy for Bund cheapest-to-deliver bond (Table 3).

We used the Bund option contract expiring 3 weeks after the last day of the study, the July 2005 contract, rather than a longer-dated option, because the shorter contract is more sensitive to expected moves in the immediate future. Implied volatilities were calculated by using a 260-day annualization factor. The correlation between group average daily cortisol levels and July implied volatility during the study gave $r^2 = 0.73$. However, it is normal for options traders on Friday afternoon to reprice options to Sunday evening, so as not to count the 2 weekend days, when the market is closed. This practice is designed to eliminate the weekend effect on options prices and gain a clearer picture of the market's expectation of volatility when the market reopens in Tokyo on Sunday evening. We followed this convention to derive implied volatilities on the 2 Fridays during the study. When we did so, the correlation between implied volatility and group average cortisol rose, with $r^2 = 0.86$, as reported above.

ACKNOWLEDGMENTS. We thank Linda Wilbrecht and Casimir Wierzynski for discussions at every stage of this research; Gavin Gobby, Ollie Jones, Matt O'Brien, and Emmanuel Roman for help with the sampling protocol; Sarah Cleary and Helen Shiers for the assays; Ed Cass, Neil Lee, Wayne Felson, Julian Day, Fred Suria, Brian Pedersen, Chris McGibbon, Stan Lasic, and Geoff Meeks for help with the financial data; John Mighton, Barry Keever, Barry Everitt, Yorgos Christopoulos, Philippe Tobler, and Aldo Rustichini for comments on the manuscript; Tim Croude for the GEE analysis; and the traders for their cooperation.

**It has been suggested by a reviewer that these steroid-feedback loops may be relevant to explaining why market volatility tends to come in waves, a phenomenon economists term autoregressive conditional heteroskedasticity (ARCH) (36).

1. Archer J (2006) *Neurosci Biobehav Rev* 30:319–345.
2. Booth A, Shelley G, Mazur A, Tharp G, Kittok R (1989) *Horm Behav* 23:556–571.
3. Chase I, Costanza B, Dugatkin L (1994) *Anim Behav* 48:393–400.
4. Oyegbile T, Marler C (2005) *Horm Behav* 48:259–267.
5. Hennessey J, Levine S (1979) *Prog Psychobiol Physiol Psychol* 8:133–178.
6. Erikson K, Drevets W, Schulkin J (2003) *Neurosci Biobehav Rev* 27:233–246.
7. Lupien S, McEwen B (1997) *Brain Res Rev* 24:1–27.
8. Herbert J, Goodyer I, Grossman A, Hastings M, de Kloet R, Lightman S, Lupien S, Roozendaal B, Seckl J (2006) *J Endocrinol* 18:393–411.
9. Lo A, Repin D (2002) *J Cognit Neurosci* 14:323–339.
10. Granger D, Schwartz E, Booth A, Arentz M (1999) *Horm Behav* 35:18–27.
11. Ehrmann M, Fratzscher M (2002) *ECB Working Paper*, no 200.
12. Fornari F (2004) *BIS Q Rev* Sept 79–86.
13. De Martino B, Kumaran D, Seymour B, Dolan R (2006) *Science* 313:684–687.
14. Hsu M, Bhatt M, Adolphs R, Tranel D, Camerer C (2005) *Science* 310:1680–1683.
15. Dickhaut J, McCabe K, Nagode J, Rustichini A, Smith K, Pardo J (2003) *Proc Natl Acad Sci USA* 100:3536–3541.
16. Kuhnen C, Knutson B (2005) *Neuron* 47:763–770.
17. Matthews S, Simmons A, Lane S, Paulus M (2004) *NeuroReport* 15:2123–2127.
18. Dreher J, Schmidt P, Kohn P, Furman D, Rubiow D, Berman K (2007) *Proc Natl Acad Sci USA* 104:2465–2470.
19. McEwen B (2001) *Ann NY Acad Sci* 935:42–49.
20. Andrew R, Rogers L (1972) *Nature* 237:343–346.
21. Booth A, Johnson D, Granger D (1999) *J Behav Med* 22:1–19.
22. Boissy A, Bouissou M (1994) *Horm Behav* 28:66–83.
23. Hermans E, Putman P, Baas J, Koppeschaar H, van Honk J (2006) *Biol Psychiatry* 59:872–874.
24. Dufty A (1989) *Horm Behav* 23:185–193.
25. Daitzman R, Zuckerman M (1980) *Pers Individ Differ* 1:103–110.
26. Pope H, Kouri E, Hudson J (2000) *Arch Gen Psychiatry* 57:113–140.
27. van Honk J, Schutter D, Hermans E, Putman P, Tuiten A, Koppeschaar H (2004) *Psychoneuroendocrinology* 29:937–943.
28. Reavis R, Overman W (2001) *Behav Neurosci* 115:196–206.
29. Schroeder J, Packard M (2000) *Neurosci Lett* 282:17–20.
30. Frye C, Rhodes M, Rosellini R, Svare B (2002) *Pharmacol Biochem Behav* 74:119–127.
31. Camerer C, Fehr E (2006) *Science* 311:47–52.
32. Joels M, Pu Z, Wiegert O, Oitzl M, Krugers H (2006) *Trends Cognit Sci* 10:152–158.
33. Korte S (2001) *Neurosci Biobehav Rev* 25:117–142.
34. McEwen B (1998) *Ann NY Acad Sci* 840:33–44.
35. International Monetary Fund (2003) *Global Financial Stability Report; Market Developments and Issues* (International Monetary Fund, New York).
36. Ding Z, Granger CWJ, Engle RF (1993) *J Empir Finance* 1:83–106.
37. Lane J (1994) *Psychosom Med* 56:267–270.
38. Pruessner J, Gaab J, Hellhammer D, Lintz D, Schommer N, Kirschbaum C (1997) *Psychoneuroendocrinology* 22:615–625.
39. Hanley J, Negassa A, Edwardes M, Forrester J (2003) *Am J Epidemiol* 157:364–375.