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Abstract: This study investigated the impact of testosterone and cortisol on aggression in a crisis simulation game. We found a significant relationship between level of testosterone and aggression. Men were much more likely to engage in aggressive action than women. They were more likely to lose their fights as well. In addition, we found a significant inverse relationship between cortisol level and aggression. We end with some speculation about why we did not find victory effects in this population.

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Over the years, there has been a great deal of debate about the problem of nature versus nurture in causality: is it genetics or environment that accounts for specific behaviors? And one of the behaviors that people have been most interested in aggression and its many manifestations, including war. The implications of the proper origin suggest different strategies for intervention; if social conditions are responsible for violence, then changing certain situational institutional can reduce the incidence of death and destruction. However, if genetic predispositions and biochemical hormones play a decisive role, ethical intervention becomes more difficult to imagine.

Previous scholars have suggested that testosterone can lead to aggression directly. Others posit that testosterone really represents an ability to respond in the face of challenge; it constitutes the potential for action more than action itself. Cognitive and social attributions and mediators remain decisive in whether challenge leads to actual physical aggression or not. Critical among these factors is whether there is a face-to-face challenge over status; such dominance strivings appear to present particularly conducive circumstances for the emergence of violence between male foes. In addition, cortisol, the so-called stress hormone, has been found to correlate inversely with aggressive action. In this experiment, we begin to test the impact of these two important hormones on aggressive action in a simulated crisis game.

<u>Literature Review and Hypotheses</u>

Testosterone exists in both men and women. In both sexes, it exerts the same effects of building muscle and increasing libido. However, male testosterone tends to run about five to ten times higher than the level of women, on average. Testosterone has been shown to be a stable over time in individuals and to vary with a predictable circadian rhythm across individuals, such that levels are highest in the mornings (Dai et al., 1981). Social factors can help explain some of the difference in testosterone levels between individuals, but not within a given individual (Gray et al., in press). Over 40% of the variance in individual levels of testosterone derives from heredity (Meikel et al., 1989). This finding supports the old adage of "like father, like son."

Testosterone and Age

The relationship between age and testosterone has been well established in both animal and human males. Most significantly, levels of serum testosterone peak in late adolescence and early adulthood, and decline precipitously after that (Dabbs, 1990). In fact, the most significant relationships between testosterone and other factors appears to be age and obesity. Other factors, including physical activity, and alcohol use, do not appear related. Smoking relates to testosterone levels only through its correlation with age (Dai et al, 1981). The one time that age adjusted testosterone appears to vary, and increase, over time, involves the years surrounding divorce (Mazur & Michalek, 1998). This correlates with well documented increases in domestic abuse during the time surrounding divorce (Mazur & Michalek, 1998; Wilson & Daly, 1993). As a result of these previous studies, we test the hypothesis that:

H_1: Younger subjects will have higher testosterone.

Testosterone and Aggressive Action

Testosterone levels have been linked with aggression (for a review, see Meyer-Balhberg, 1981), dominance (Gray, 1991), antisocial behavior, including fighting, drug abuse, and nontraffic arrests (Dabbs & Morris, 1990), and sensation seeking (Daitzman & Zuckerman, 1980). Indeed, a great debate about the relationship between testosterone and aggression has raged in the psychological, anthropological and sociological literatures. Clear evidence exists that testosterone correlates to dominance rank in male chimpanzees (Muller & Wrangham, 2001). Further studies find that heightened testosterone increases aggression in animals (Monaghan & Glickman, 1992; Svare, 1983).

Some primate models suggest two different forms of aggression, defensive and offensive. Kalin (1999) suggests that a unique neural mechanism underlies each type. He posits that defensive aggression is fear-based, controlled by the right frontal lobe of the brain, and correlated with high cortisol levels. On the other hand, offensive or impulsive forms of aggression is associated with lower levels of serotonin and cortisol, and higher levels of testosterone. He argues that all forms of aggression are affected by environmental factors, and, as with humans, greatest risk is conferred by serious disruptions in the mother-child bond.

Some studies have found a direct relationship between higher levels of testosterone and higher levels of aggressiveness in humans as well, even within normal ranges (Gerra et al., 1997). In some studies, testosterone correlates with anger and verbal aggression in men (Von Der et al., 2002). In others, testosterone significantly relates to levels of both verbal and physical aggression (Soler et al., 2000). Experimentally inducing increased testosterone levels seems to confirm this effect. While an additional dose of 300 mg. per week appears not to exert an effect on behavior, dosages in excess of 500 mg. per week seems to induce noticeable increases in psychiatric symptoms, including increased manic and aggressive behaviors (Pope et. al, 2000). In a nice twist on the old Milgram paradigm, subjects with higher levels of testosterone showed greater willingness to engage in physical aggressiveness by shocking an increasingly challenging fictitious opponent (Berman et al., 1993).

Testosterone clearly has an impact in competitive settings. Male judo competitors, for example, displayed a direct relationship between levels of testosterone and number of threats, fights and attacks (Salvador et al., 1999). In further studies with this same population, Salvador et al. (2003, 364) found that the group with higher testosterone also performed better in competition; the authors suggest that testosterone provides “an adaptive neurobiological response to competition.” The evidence for the impact of testosterone on competition in women is less well-explored. One study found that women with higher testosterone were more likely to express their competitive feelings through verbal aggression. Interestingly, women with higher levels of estrogen were less like to compete with others over athletics than their lower estrogen counterparts (Casdan, 2003). This might suggest that pill use, which artificially effects estrogen levels, could alter female competitive athletic performance.

Others claim, however, that few studies have found a direct link between testosterone levels and direct aggression in primates and humans (Albert et al., 1993; Archer, 1991). They suggest that the most accurate way to conceptualize the relationship between testosterone and behavior involves the manifestation of dominance, especially in one-on-one, face-to-face status-based interactions (Mazur, 1985; Dabbs et al., 1997). In one study of social dominance in boys, for example, Rowe et al. (2004) found that DSM-IV symptoms of conduct disorder increased around the time of adolescence, and that these age trends were driven, at least in part, by increasing levels of circulating testosterone. He found no relationship between physical violence and high testosterone levels. Oftentimes, however, these grabs for dominance manifest in the form of direct aggression. One large study, involving 1709 men, demonstrated a relationship between personality profiles of dominance with some aggression and elevated levels of androgens, including testosterone (Gray, 1991).

On a larger sociological level, there remains absolutely no question that men commit violent crimes in hugely greater numbers than women. In one systematic sample of homicides in Chicago and Detroit, for example, over 85% of homicides were committed by men. Interestingly, over 80% of the victims were also male (Daly & Wilson, 1988). This pattern of vastly higher rates of same-sex male homicide seems to hold in all cultures over time (Buss & Shackelford, 1997).

While it may be difficult to prove a direct relationship between testosterone and criminality, behavior which can be exacerbated by high levels of testosterone tend to get men in trouble with the law. Prison studies, for example, show that high testosterone men commit more violent crimes against other people, as opposed to property crimes, and act out more than lower testosterone men (Dabbs et al, 1995). This remains consistent with the notion that face to face status interactions with other high testosterone males elicits greater chances for violence to erupt. Further, men convicted of domestic violence also possess higher levels of testosterone and display greater physical violence than healthy controls (George et al., 2001).

Testosterone also correlates with sensation seeking. Testosterone appears to correlate with high disinhibitory instincts, which is a sensation seeking subscale. In one study, testosterone related to personality profiles including stable extroversion. It also correlated with impulsivity and high levels of heterosexual contact. Indeed, high testosterone remains significantly correlated with antisocial behavior, high risk behavior, unemployment and low paying jobs, and being unmarried (Booth, Johnson & Granger, 1999).

On the other hand, lower levels of testosterone correlate with self -control and social conformity (Daitzman & Zuckerman, 1980). In fact, lower levels of testosterone appear to correlated with several kinds of pro-social behavior. Specifically, low testosterone men have a more pleasant and friendly manner, including smiling more (Dabbs, 1997), and maintain much more positive relationships with their families (Julian & McKenry, 1989; Booth & Dabbs, 1993).

Social and personality factors appear to be able to mediate at least some of the effects of testosterone on behavior. In one study of 17 professional basketball players, subjects who attributed their victory more to luck than skill showed lower levels of salivary testosterone than their more egotistical counterparts (Gonzalez-Bono et al., 2000). Further, high hostility subjects who were harassed during their performance of a solvable experimental task demonstrated higher blood pressure, heart rate, testosterone and cortisol relative to their low hostility counterparts or those who were not harassed (Suarez et al., 1998).

Why should humans, and men in particular, have evolved in such a way as to be pre-disposed toward dominance, and its sequalae of aggression? One explanation suggests that testosterone provides some immunity against illness (Granger et al., 2000). Another suggests that it might prove advantageous in military conflict, enhancing the chances of winning in battle (Wrangham). Buss & Shackelford (1997) argue for an evolutionary understanding of human aggression. They suggest that aggression is context-sensitive and that human males evolved to adaptively handle certain problems in social living and interaction. In particular, they posit that aggression may have emerged as a solution to at least seven such problems: including stealing other's resources; defending oneself; penalizing same-sex rivals for attractive mates; negotiating power and status hierarchies; deterring others from future attacks; preventing mates from engaging in sexual infidelity; and limiting resources spent on raising someone else's children. Given that testosterone appears to be related to aggression and dominance behaviors, we hypothesize that:

$H_{2:}$ Individuals with higher levels of testosterone will be more likely to engage in aggressive action than those who possess relatively lower levels of testosterone.

Cortisol and Aggressive Action

Cortisol is colloquially known as the stress hormone, and indeed cortisol is essential for orchestrating a person's physical responses to environmental stresses. Most corticosteroids are produced by the adrenals, which are almond sized glands which sit atop each kidney. Most receptors lie in the limbic system, the part of the brain responsible for a great deal of emotional processing, among other tasks. There appear to be two modes of function for this system. The first is a kind of rapid response system, which organizes behavioral responses to stress through the sympathetic nervous system and the hypothalamic-pituitary-adrenal (HPA) system. This system appears to keep the body in a steady physical state. The second system operates more slowly, and is responsible for longer term adaptation. This second system seems indicated in the maintenance and management of long term energy storage. Imbalances in either system caused by stress or other sources can disrupt neurological pathways in ways which can cause depression, anxiety, and problems with cognition, emotion, or aggression (deKloet, 2003).

Previous studies have found that environmental factors can unduly affect cortisol levels throughout the day. Teachers with high job stress manifest higher morning levels of cortisol than their low job stress counterparts. This effect was exacerbated in subjects with high anger. In this study, cortisol levels fell throughout the day, indicating that as the level of job related stress dissipated as the day came to an end, elevated levels of cortisol declined commensurately. Regardless of job stress, women displayed higher morning cortisol levels (Steptoe et al., 2000). Similarly, in a study of crew fatigue in simulated long duration B-1b bomber missions, cortisol was highest, as was anger, confusion, tension and depression, in the first of three 36 hour missions (French et al., 1994). Clearly, and unsurprisingly, a novel situation generates more stress than a familiar one.

Overall, cortisol levels appear to be inversely related to aggression and anger. In one study of 38 boys referred for their disruptive behavior, low cortisol boys showed three times more aggressive symptoms and were judged three times more often by their peers as being the most aggressive (McBurnett, 2001). A five year longitudinal study of adolescent boys produced similar results. In this study, among 314 boys between the ages of 15-17, low cortisol in preadolescence predicted higher levels of aggressive behavior five years later. The authors argued that low self-control was the mediated personality factor between low levels of cortisol and high levels of aggression (Shoal et al., 2003).

Less work has been conducted on the relationship between females and cortisol, but the general findings in males appears to hold true for women as well. In one study of 84 girls, those with lower levels of cortisol were more likely to suffer from conduct disorders. In fact, having a conduct disorder accounted for 10% of the variance in cortisol levels. This was true even in a population where girls with conduct disorder did not have any other psychiatric disorders (Pajer et al., 2001). Further, in a study of competitive female swimmers, cortisol was higher in swimmers than controls. However, when swimmers were overtrained, their cortisol levels correlated with depression and mood in those with decreased performance (O’Connor, 1989).

Given these previous findings, we hypothesize that:

H_3: Subjects with lower levels of cortisol will be more likely to engage in aggressive action than those with higher levels.

Testosterone and Relationship

Age is not the only factor that has been shown to exert a dramatic impact on testosterone levels. Marriage and parenthood lower testosterone significantly as well, at least in men. In the most systematic and careful investigation of this phenomenon, Gray et al. (2002) found that married men had significantly lower testosterone than unmarried men. Even among married men, those with greater involvement, interaction, and time spent with their wives had lower testosterone levels than their less engaged married counterparts. Fathers also had lower testosterone levels than their single counterparts. In fact, Gray et al. (2002) found that the only significant predictor of testosterone levels in their evening sample was relationship status. Other factors which they examined, including body mass index, exercise and stress did not achieve significance. They argue that their findings support theories (Lancaster & Kaplan, 1992; Wingfield et al., 1990) which suggest a direct trade-off in males between competitive behaviors, supported by higher testosterone, and mating and parenting behaviors, which appear to precipitate drops in testosterone.

These results find support in other areas of the literature as well. Mazur & Michalek (1998) found that age adjusted testosterone rates were lower in married men than in those who were single and divorced. In fact, testosterone levels appeared to peak four to eight years prior to marriage, and declined beginning shortly after marriage. In another study of 4, 462 male military personnel, Booth & Dabbs (1993) found that those men with higher testosterone levels were less likely to marry and more likely to divorce if married. If married, men with high testosterone proved more likely to leave the marriage because of trouble in the marriage involving their own infidelity, hitting or throwing things at their wives, and a lower quality of marital interaction.

Marriage clearly exerts an impact on criminality as well, possibly through the mechanism of decreased testosterone in married men. For example, Daly & Wilson (1990) found that married men were less likely than their single counterparts of the same age to kill an unrelated male. In an earlier study, Wilson & Daly (1985) found that in Detroit, 73% of male murders and 69% of male victims were unmarried, although the base rate of same age unmarried men in Detroit at the time was 43%. In a larger study examining same sex murder of unrelated people from Canada (1974-93), England (1977-1986), Chicago (1965-81) and Detroit (1972), Daly & Wilson (1990) again found both that murder rates drastically declined as men aged (peak murder rates in all samples was early 20's), and that married men were much less likely to commit murder than unmarried men.   Divorced men, as the data from Mazur & Michalek (1993) would suggest, possess homicide rates which are most similar to single men.   In another study of criminal behavior and deviance over the life cycle, Sampson & Laub (1990) found that strong marital attachments inhibited adult criminal and deviant behavior.

Therefore, we hypothesize that:

$H_{4:}$ People in long term relationships will be less likely to engage in war than their unmarried or divorced counterparts.

Victory Effects

In previous literature, testosterone often displays a characteristic rise and fall relative to competition. Typically, testosterone rises in both players prior to competition, and then rises slowly throughout competition until the end, at which point the winner and loser diverge. The loser's testosterone drops while the winner's testosterone rises. The most famous examples of this effect is probably that found by Mazur, Booth & Dabbs (1989) when they reported that male chess players demonstrated a rise in testosterone subsequent to winning competitions, while losers' levels of testosterone fell. Other earlier studies have suggested that similar dynamics occur in wrestling (Elias, 1981), reaction time tasks (Gladue et al., 1989), and tennis (Booth et al., 1989) . Mazur & Lamb (1980) found that male winners in a game of tennis, and men who had just been awarded medical degrees, showed rises in testosterone, while subjects who won in a random lottery did not. The authors suggest that testosterone rises only when a man feels that his status has improved as a result of his own efforts. One important factor to note about each of these studies is that they only examined the effect of testosterone on competition in men, not in women.

Interestingly, several more recent studies, and studies involving women, fall to demonstrate the expected victory effect documented earlier. One earlier study among male judo competitors failed to show expected victory effects. Curiously, members in the regional team did increase testosterone relative to non-members, and a past history of successful sporting competition was positively and significantly related to rises in testosterone during competition (Salvador et al., 1987). But testosterone levels of winners and losers did not diverge subsequent to play. A similar study of male judo players found an even more unexpected finding; losers' testosterone was significantly greater than that found in winners (Filaire et al., 2001).

In a study specifically designed to examine the effect of testosterone and cortisol in women's competition, Bateup et al. (2002) found that pre-game levels of testosterone were elevated relative to baseline, and were correlated with bonding, aggressiveness and focus. They were not related to perceptions of the opponent's skill. While post-game levels of both testosterone and cortisol were higher than pre-game in a group of 17 nationally recognized female college rugby players, these effects were unrelated to winning or losing, or to perceptions of either personal performance or the opponent's threat. Cortisol changes during the game were positively related to whether the opponent was more of a challenge than expected, and negatively related to losing.

In later studies with males, Mazur et al., (1997) also failed to find the expected victory effect in a study of men and women in a same-sex video-game contest. They found that only male testosterone rose prior to competition, and that female testosterone continually declined throughout the course of the study. Finally, this study reports that female testosterone and cortisol work in parallel in women, but not in men. They conclude that testosterone works differently in competition in men and women.

Based on this divergent literature, we test two hypotheses.

H_5: Testosterone levels will increase over play, at the end of which losers' levels will fall while winners' levels will rise.

H_6: Women and men will display differing responses of testosterone to competition.

Methods

This study used an experimental laboratory simulation methodology to investigate these hypotheses

Subjects

This study involved 180 subjects who were recruited from the Harvard Business School experimental subject pool. We were able to obtain usable testosterone samples from 180 in the baseline round; 78 women and 102 men. We had 134 samples in the middle round, 59 women and 75 men. And we had 179 samples in the final round, 77 women and 102 men. This discrepancy is because samples taken when the game ended before round three were treated as final, not middle round, samples. Our sample had the following racial composition: 60.8% Causasian, 19.4% Asian, 11.3% African-American, 3.2% Hispanic, 1.1% Native American and 4.3% Other. Ages ranged between 18-65, with a mean of 22.31. The oldest woman was 48, while the oldest man was 65. Only 2 subjects had children, and so we were not able to conduct any analysis on the relationship between parenthood and testosterone levels. Table 1 provides the summary statistics for subjects in the analysis.

We received human subjects permission for this experiment from the Harvard Institutional Review Board. There was absolutely no deception in this experiment. All participants signed informed consent forms prior to their participation, and were told they could leave the study at any time without penalty. All students were volunteers who received cash payments of either $20 or $30, depending on how well they performed during the game.

Table 1. Summary statistics for subjects in the analysis.

Case Summaries

GENDER		T1	T2	T3	C1	C2	C3	AGE	Relationship	CHILDREN
Females	N	78	59	77	78	59	77	79	79	79
	Mean	77.72	50.19	45.16	7496.79	6907.12	7227.40	22.99	1.81	2.53E-02
	Std. Deviation	60.29	58.56	40.33	4425.98	4408.71	5067.27	5.37	1.27	.23
	Minimum	14	14	14	880	880	1460	18	Single	0
	Maximum	323	304	217	22070	23410	34920	48	Dating only	2
	% of Total N	43.3%	44.0%	43.0%	43.1%	44.4%	42.8%	42.5%	42.5%	42.5%
Males	N	102	75	102	103	74	103	107	107	107
	Mean	341.50	241.75	244.75	7181.07	7424.19	6690.97	21.80	1.79	9.35E-03
	Std. Deviation	202.08	140.32	145.44	4844.74	5182.69	5057.86	5.58	1.26	9.67E-02
	Minimum	45	28	32	1300	1770	880	18	Single	0
	Maximum	1208	708	710	28550	36570	33440	65	Dating only	1
	% of Total N	56.7%	56.0%	57.0%	56.9%	55.6%	57.2%	57.5%	57.5%	57.5%
Total	N	180	134	179	181	133	180	186	186	186
	Mean	227.19	157.40	158.89	7317.13	7194.81	6920.44	22.31	1.80	1.61E-02
	Std. Deviation	204.42	146.84	150.05	4658.86	4843.70	5054.73	5.51	1.26	.16
	Minimum	14	14	14	880	880	880	18	Single	0
	Maximum	1208	708	710	28550	36570	34920	65	Dating only	2
	% of Total N	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Procedure

This simulation game was complex in nature. When students arrived, they were given informed consent forms to read and sign. After they had done so, they were given Extra original flavor chewing gum to stimulate salivation. They then spit into a 15 ml. collection vial pre-treated with sodium azide, an anti-bacterial agent. Samples were temporary stored at room temperature, after which they are immediately frozen, and thawed 24 hours before being assayed. Samples were assayed at the Harvard University Reproductive Ecology laboratory, following a modified version of an ^{125}I-based, double-antibody radioimmunoassay kit (DSL-4100) produced by Diagnostic Systems Laboratory, Inc. (Webster, TX). This protocol is described in detail in Gray et al. (2004). Subject samples were assigned to 8 different assay groups; assays 1 through 3 were exactly sex-balanced, whereas 4 through 8 had slightly more males than females. Every effort was made to measure testosterone and cortisol levels of both partners in a dyad within the same assay to make their results more directly comparable. The interassay coefficients of variation for low and high pools were 20.2% and 5.3% respectively.

When they had filled one vial, subjects were seated before a computer terminal. Before the actual game began, subjects filled out a number of questionnaires, including demographic information, and several mood inventories. Subjects filled out scales which included a depression inventory, a self-esteem scale, a narcissism questionnaire, measures of stress, fear, anger and a social dominance orientation survey. Once the subject had completed these inventories, the actual game began.

In this game, subjects were paired in either same-sex or mixed-sex dyads. These dyads were created through formal random number assignment protocols. Once the real-time game began, students read instructions that asked them to role play the leader of a country in conflict with a neighbor over newly discovered diamond mines on disputed territory. Mine workers had been ambushed and killed and subject-leaders were told to handle this crisis.

This game ran for six rounds, but subjects remained unaware of how many rounds the game would go until after they had finished. In each round, subjects undertook a number of different tasks. In the starting round, each person was given 100 million dollars, which was also given at the start of each successive new round. The subjects could keep that money as cash, they could buy army battalions with them for 10 million dollars a piece, or they could allocate their money into industrial production. The winner of the game was the one who ended up with the most industrial production in their account at the end of the game. Subjects could dismantle weapons for cash or industry at a discounted rate of 50%; for example, a person who bought one battalion for 10 million dollars would get 5 million if she chose to disarm. The game was structured in such a way that it was possible to win the game either by negotiating or by going to war and winning. However, there was an inherently greater risk in going to war because the probability of losing always existed, realistically.

After making these choices, each subject had to take an action that included doing nothing, negotiating, making a threat, going to or continuing war, or surrendering. Only one subject very surrendered, and he was an older man in the latest experiment we ran. At 8:45, it became clear that he would rather surrender, and go home, than continue to engage with a 50% probability of earning an additional $10. If subjects chose to negotiate, they had to make allocation decisions about how to divide up the money from the diamond mines. If they went to war, the computer calculated who won and who lost how much based on a consistent set of probabilities which varied somewhat by experimental condition. After a victory, the loser lost all his battalions and an equal amount of money (each battalion generates 10 million) was transferred from his industrial production account into that of the winner. If a player lost all of his military resources in a war, then the game ended. In addition, if players put all their money into their army without putting any money into industrial production, there was a 10% chance, which they were informed of prior to the game, of a coup that would overthrow their government. This eventuality did not take place in this running of the game.

They also had to write a message to the other side, and, in later rounds, read a message their opponent had sent the previous round. They were required to tell their partners how many battalions they had acquired, but they were allowed to bluff +/- 30% of their true value if they wished. In addition, subjects filled out subjective assessments of their own, and their partners' levels of aggressiveness, hostility, trustworthiness, competitiveness, intelligence and skill. Finally, students wrote notes, seen only by the experimenters, about why they had taken the actions and made the choices they did. They were required to do all these things in five minutes per round, to simulate the time pressure of real-life decision making.

Midway through the game, we took a second testosterone sample from all subjects, except from those for whom the game had ended prior to the third round. At the end of the game, subjects found out whether they won or lost the game, after which a third saliva sample was taken. Those who won received an additional $10 in payment for their participation in the experiment, which they knew about in advance. They also filled out some final questionnaires about the game.

Measures

As noted above, many of the measures were designed specifically for use in this experiment, including most of the measures of decision and action during the game. However, many of the initial personality inventories came from established questionnaires. The Beck depression inventory was used. We administered the Rosenberg self-esteem measure, as well as a standard narcissism measure. We used a measure of fear and anger given to us by Paul Ekman. We used a standard stress measure, and the short version of the social dominance orientation scale (Pratto et al., 1994). All scales are available from the authors upon request.

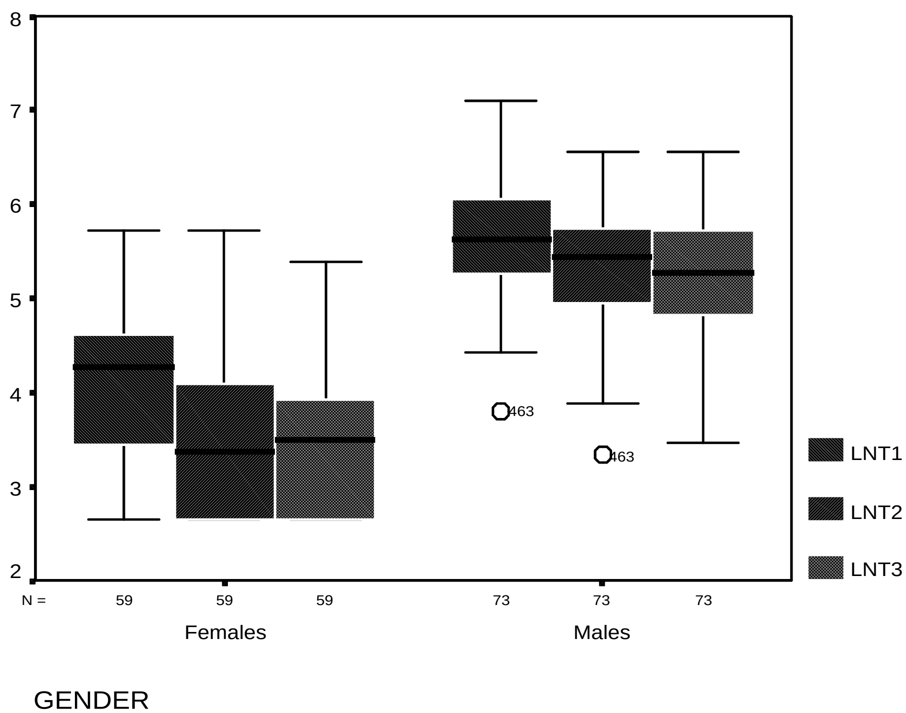
<u>Results</u>

All raw testosterone and cortisol data were positively skewed. We therefore transformed them to their natural logarithm, which produced much more satisfactory normally distributed variables allowing a greater range of statistical procedures. One subject's initial testosterone reading was eliminated from the dataset because it reached the maximum on the scale (>> 3 SD above the mean) and is suspected to have been contaminated.

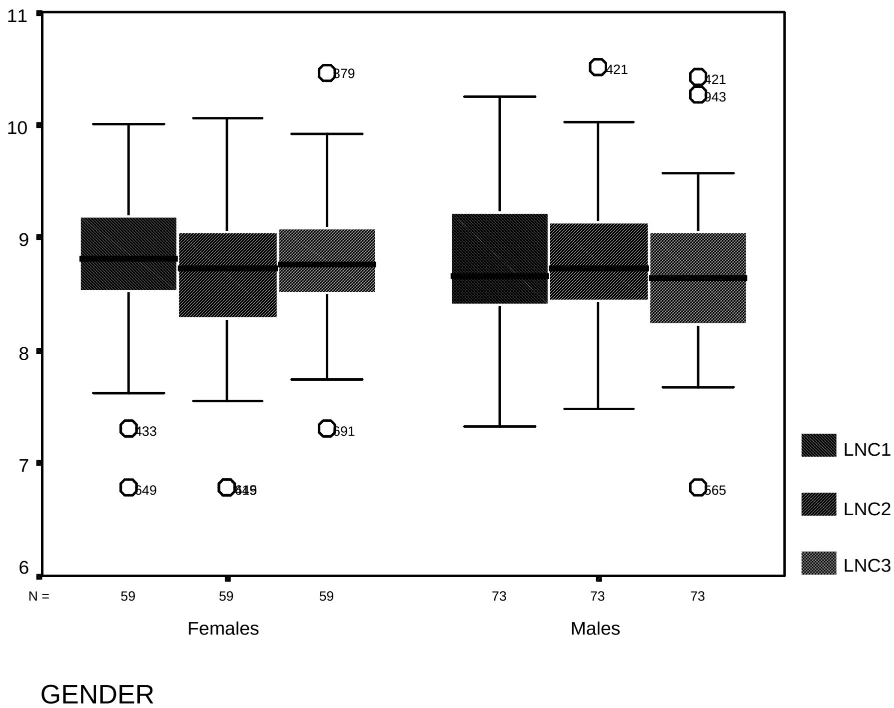
Overall testosterone and cortisol levels

Below are graphs depicting overall levels of testosterone and cortisol in our subjects over time, divided into male and female groups.

Ln Testosterone samples 1,2,3



Ln Cortisol samples 1,2,3



Testosterone and Age

We found a significant negative relationship between age and testosterone (Spearman's rank correlations detailed in Table 2). However, there were more older women in the sample than there were older men, such that a disproportionate number of young men (who typically have high testosterone levels) and a disproportionate number of older women (who typically have low testosterone levels) may have driven these correlations (we found no within-sex correlations). A general linear model, which controlled for gender, found no significant relationship between age and level of Testosterone (whether using raw age or normalized age). These conclusions were corroborated when using a normalized age variable (given a very heavy skew in raw age, this required transformation using the 3rd reciprocal root: $-1/[(\text{age})^3]$).

TABLE 2. Negative correlation between age and the three (ln) testosterone samples.

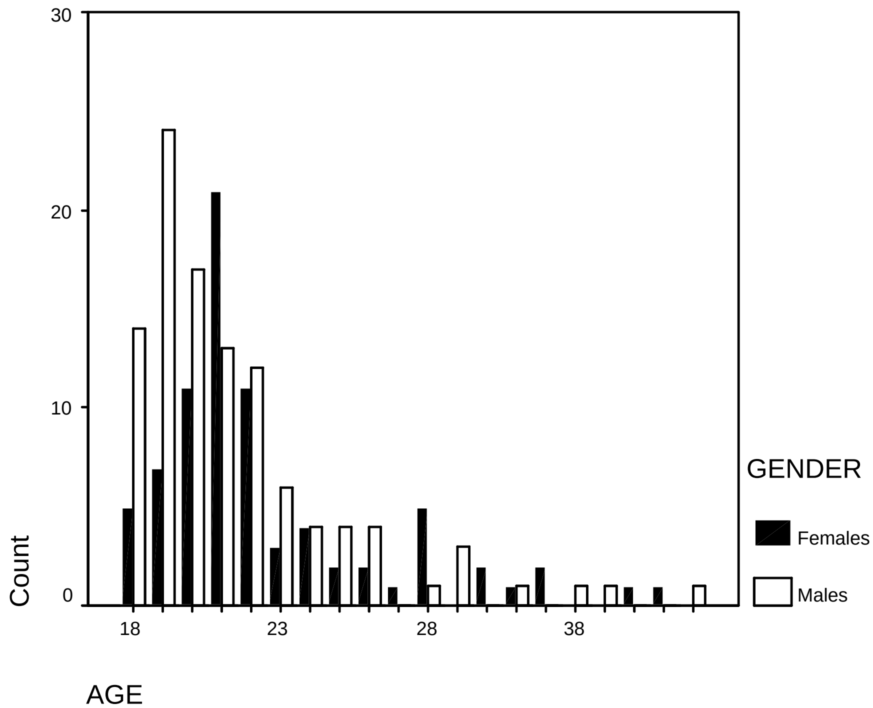
Correlations

		AGE	-1/(age)**3	LNT1	LNT2	LNT3
AGE	Correlation Coefficient	1.000	1.000**	-.152*	-.200*	-.175*
	Sig. (2-tailed)	.	.	.042	.021	.019
	N	186	186	180	133	180
-1/(age)**3	Correlation Coefficient	1.000**	1.000	-.152*	-.200*	-.175*
	Sig. (2-tailed)	.	.	.042	.021	.019
	N	186	186	180	133	180
LNT1	Correlation Coefficient	-.152*	-.152*	1.000	.877**	.880**
	Sig. (2-tailed)	.042	.042	.	.000	.000
	N	180	180	180	133	179
LNT2	Correlation Coefficient	-.200*	-.200*	.877**	1.000	.910**
	Sig. (2-tailed)	.021	.021	.000	.	.000
	N	133	133	133	133	132
LNT3	Correlation Coefficient	-.175*	-.175*	.880**	.910**	1.000
	Sig. (2-tailed)	.019	.019	.000	.000	.
	N	180	180	179	132	180

**. Correlation is significant at the .01 level (2-tailed).

*. Correlation is significant at the .05 level (2-tailed).

More younger males in the data (and more males overall)



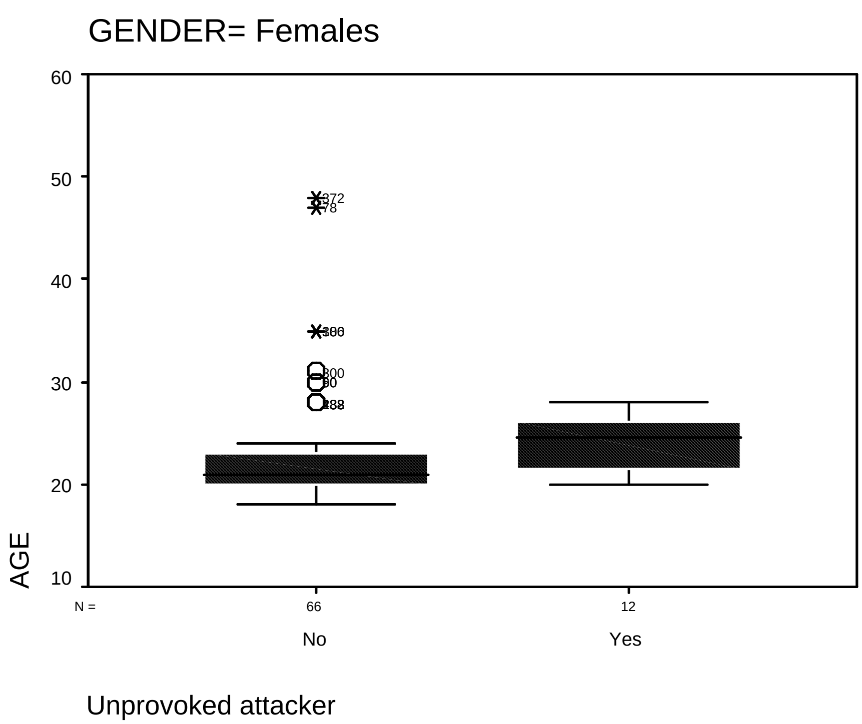
More belligerent older women

The sample size of attacking women is small, but even using a conservative test of raw age and a Mann-Whitney U-test (which makes few assumptions about distribution), those women who made unprovoked attacks were significantly older than women who did not attack (Z=-2.21, p=0.027). This was not true for men:

Test Statistics[a]

GENDER		AGE
Females	Mann-Whitney U	238.500
	Wilcoxon W	2449.500
	Z	-2.208
	Asymp. Sig. (2-tailed)	.027
Males	Mann-Whitney U	1128.000
	Wilcoxon W	3829.000
	Z	-.282
	Asymp. Sig. (2-tailed)	.778

a. Grouping Variable: Unprovoked attacker

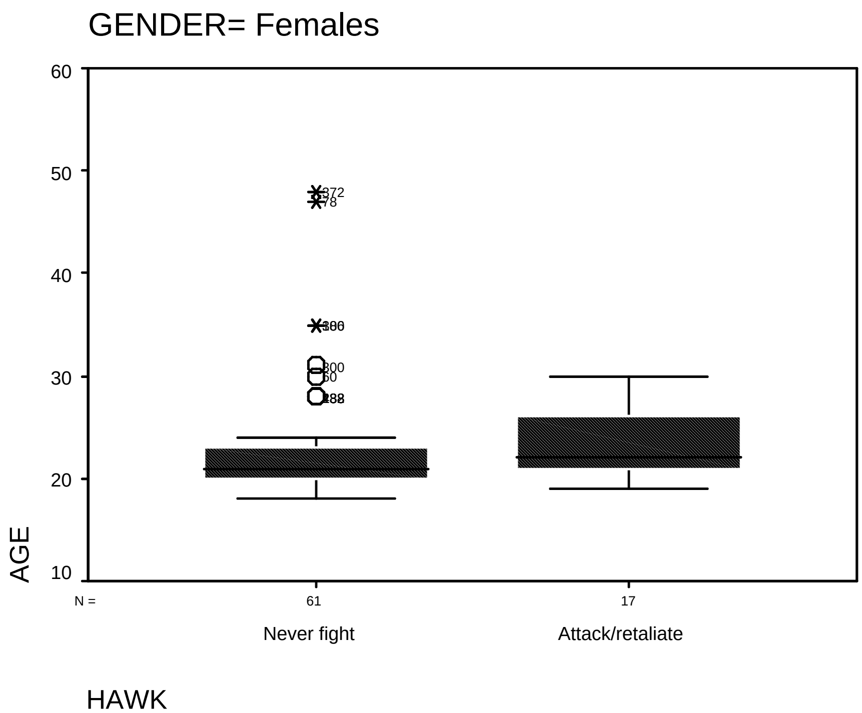


Repeating this test using normalized age and a t-test, the result is borderline significant (t=-1.98, d.f.=76, p=0.051). Older women also were more "hawkish" (meaning that they either made unprovoked attacks OR retaliated), but this was not quite significant:

Test Statistics[a]

GENDER		AGE
Females	Mann-Whitney U	376.500
	Wilcoxon W	2267.500
	Z	-1.739
	Asymp. Sig. (2-tailed)	.082
Males	Mann-Whitney U	1234.000
	Wilcoxon W	1937.000
	Z	-.163
	Asymp. Sig. (2-tailed)	.871

a. Grouping Variable: HAWK



This finding may be a result of the fact that older women are significantly less likely to be on the pill:

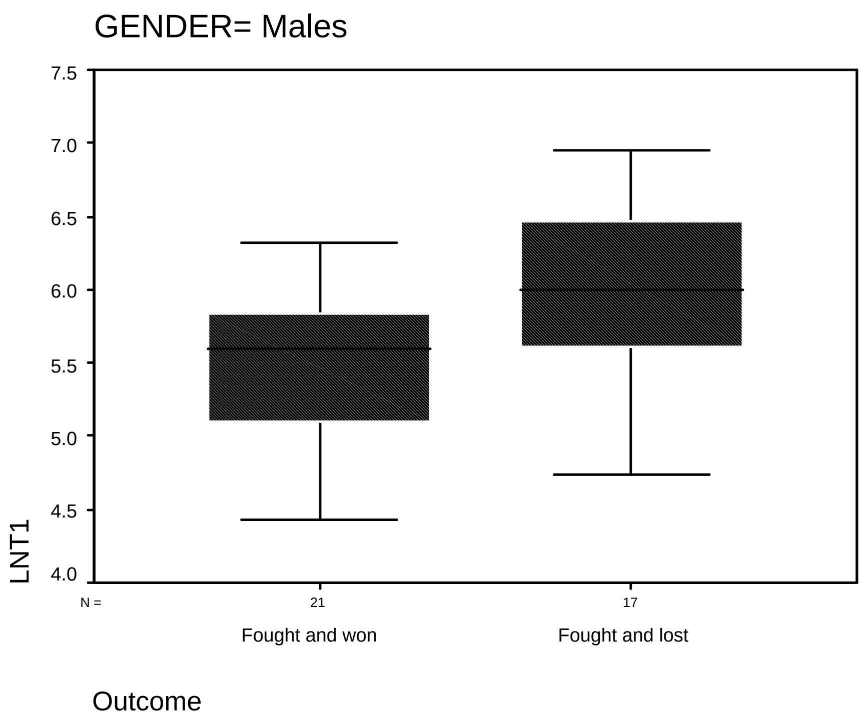
Test Statistics[a]

GENDER		AGE
Females	Mann-Whitney U	502.500
	Wilcoxon W	880.500
	Z	-2.089
	Asymp. Sig. (2-tailed)	.037

a. Grouping Variable: PILL

Testosterone and Winning

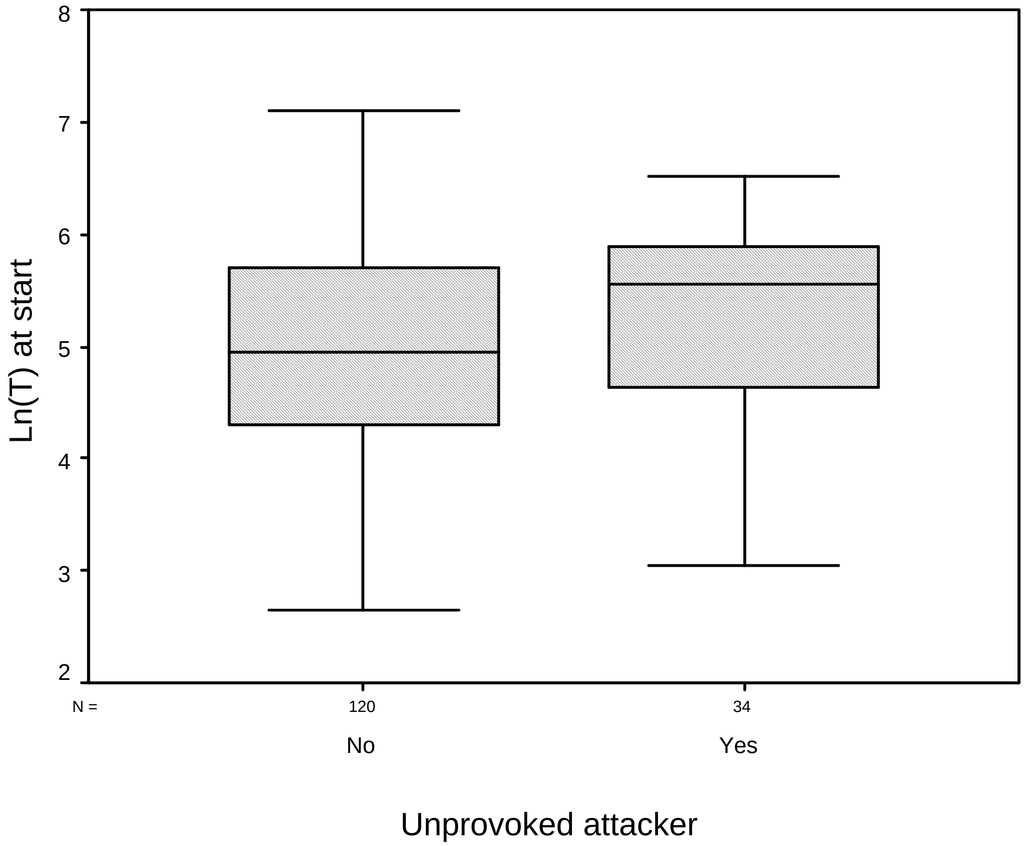
In examining the winners among those who fought, males who fought and lost had higher initial Testosterone ($t=-2.27$, d.f.=36, $p=0.029$; there is no such effect in females):



T and Aggressive Action

We used unprovoked attacks on an opponent as our dependent variable for aggression (retaliation *in response* to other's aggression may be mediated by various processes and therefore implies a weaker measure of aggressive intent). Individuals with higher levels of testosterone were more likely to make an unprovoked attack on their opponent (Figure 1; independent samples t-test: t=-1.79, d.f.=152, p=0.037, one-tailed test). There were no within-sex differences in (ln) testosterone between attackers and non-attackers (t values < 0.5, p>0.6).

FIGURE 1. Those who made unprovoked attacks on their opponent had higher initial (ln transformed) testosterone levels.



We next used binary logistic regression to examine the effect of (ln) testosterone on the probability of an unprovoked attack (a “yes” or “no” variable), while controlling for gender, age, and use of the pill. This procedure produced a model that was statistically significant in comparison to a null model containing a constant term only: *(Π*$_2$=9.86, d.f.=4, p=0.043; Cox & Snell R Square=0.062). The model correctly assigned 77.4% of the cases. Table 3 details the variables in the model equation, and their *partial* effects (that is, their effect on the model given the simultaneous influence of all the other included variables), none of which are individually significant. “B” is the effect size of each variable on the dependent variable. “Exp(B)” is the odds ratio, which is interpreted, in the case of GENDER for example, as meaning that a male case is 0.324 times more likely to be an unprovoked attacker than a female case. The lack of significance of these variables means they should not be over-interpreted in this model.

TABLE 3. Independent variables in the logistic regression on unprovoked attack.

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	LNT1	-.295	.304	.938	1	.333	.745
	AGE	.005	.036	.016	1	.898	1.005
	GENDER(1)	-1.126	.675	2.783	1	.095	.324
	PILL(1)	1.632	1.113	2.148	1	.143	5.112
	Constant	-.957	2.059	.216	1	.642	.384

a. Variable(s) entered on step 1: LNT1, AGE, GENDER, PILL.

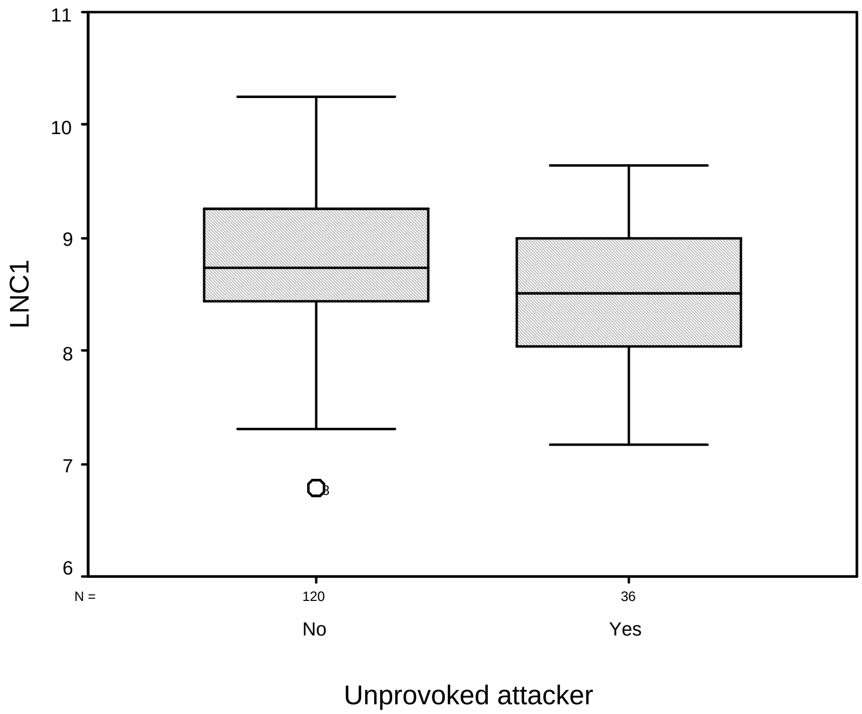
However, simple analyses of each variable's independent effects showed that males are significantly more likely to make unprovoked attacks than females (Π_2=4.77, d.f.=1, p=0.029), as are those not on the pill (Π_2=5.26, d.f.=1, p=0.022). (Ln) testosterone was already shown above to have significant effects on unprovoked attacks.

Cortisol and Aggressive Action

Individuals with *lower* levels of (ln transformed) cortisol were more likely to make an unprovoked attack on their opponent (Figure 2; independent samples t-test: t=-2.37, d.f.=154, p=0.019, two-tailed test).When split by sex, this difference disappeared among females (t=0.24, d.f.=61, p=0.81, two-tailed test), but remained significant among males (t=2.52, d.f.=91, p=0.013, two-tailed test). Lnc2 and ln c3 showed no such effect of statistical significance (though they were in the same direction).

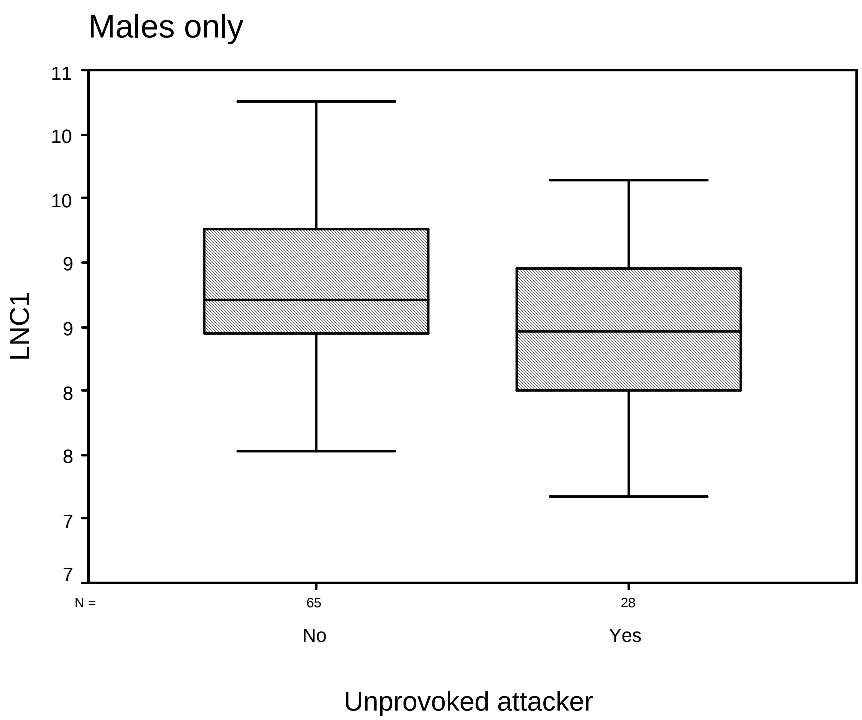
Figure 2. Those who made unprovoked attacks on their opponent had lower Ln cortisol levels among all subjects (a) and among males only (b).

(a)



11
10
9
8
7
6
LNC1
N =
120
36
No
Yes
Unprovoked attacker

(b)

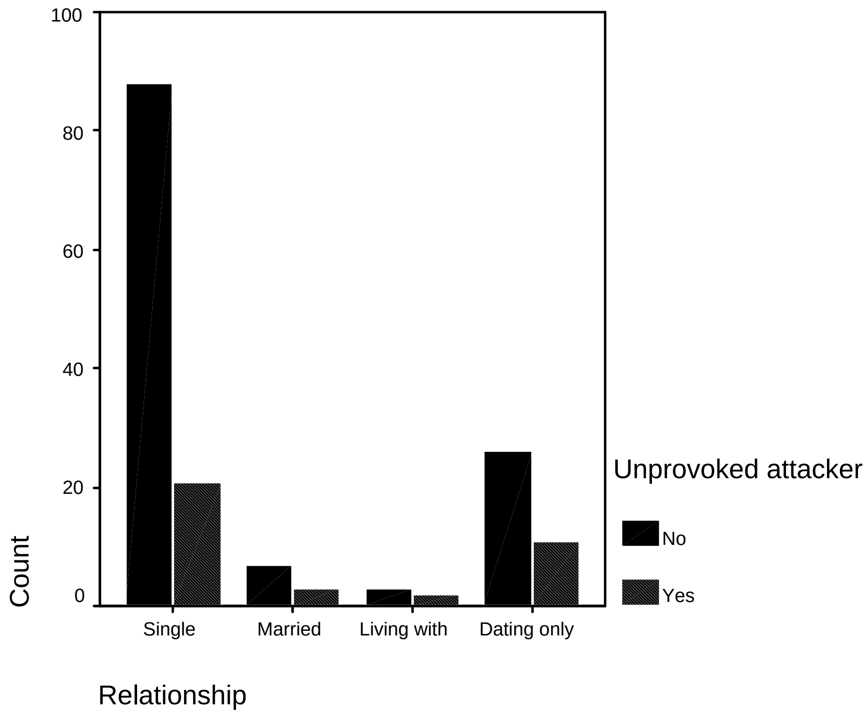


Long-term Relationships and Aggressive Acts

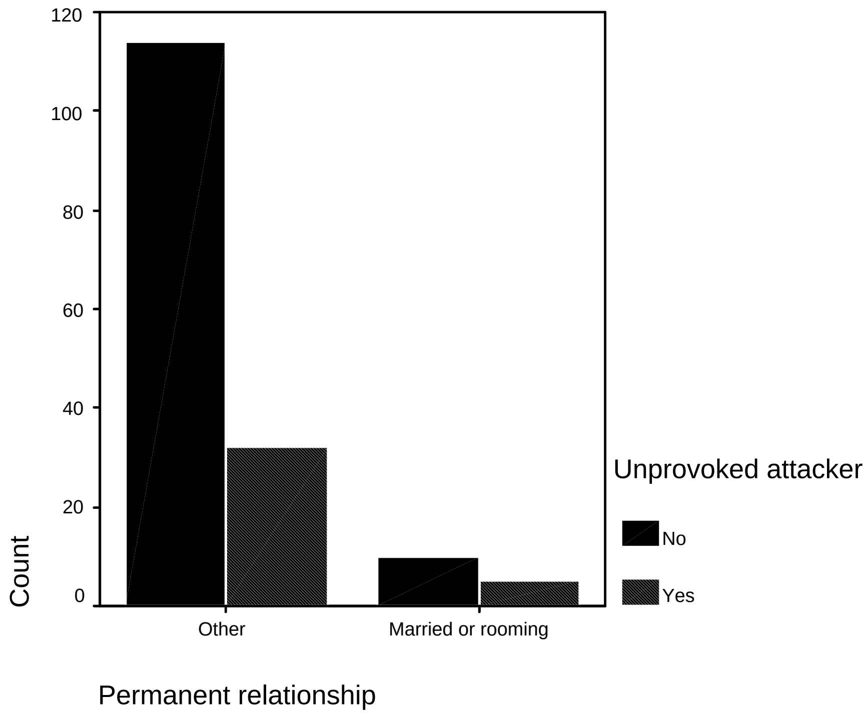
We found no relationship between subjects' type of relationship and unprovoked aggression (Chi-squared tests all non-significant). As Figure 3 shows, unprovoked attackers were approximately equally represented in all classes of relationship.

Figure 3. No difference in proportion of unprovoked attackers between classes of relationship (a) or simplified classes of relationship (b).

(a)

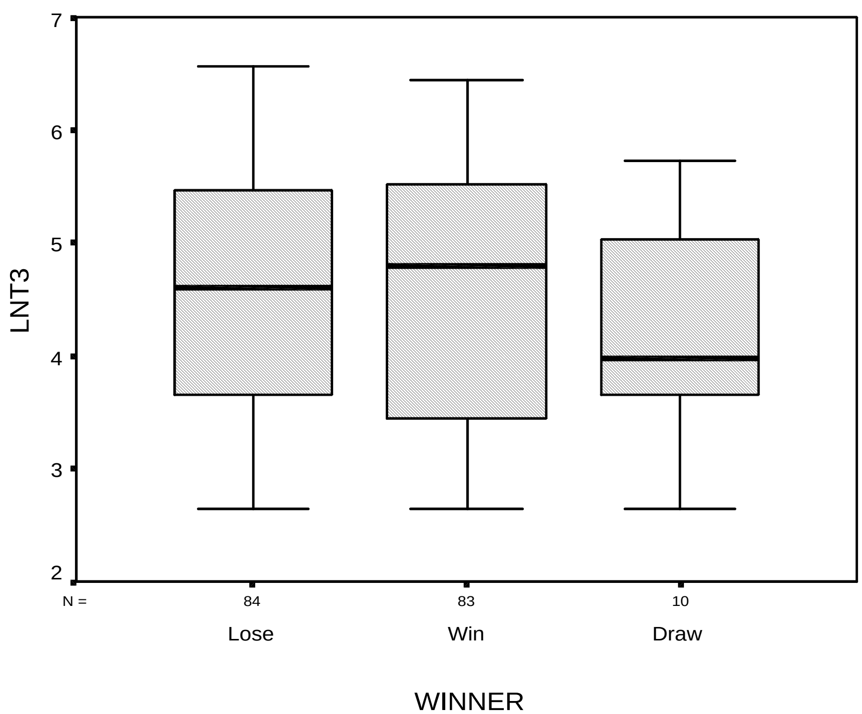

100
80
60
40
20
0
Count
Single
Married
Living with
Dating only
Relationship
Unprovoked attacker
No
Yes

(b)



Absence of Victory Effect

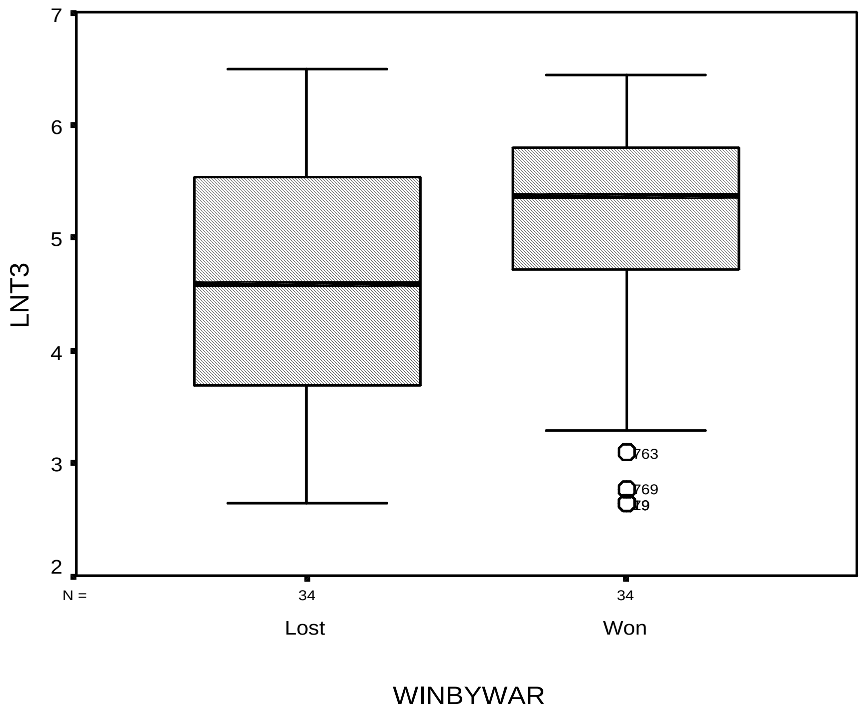
We did not find any victory effects in our data. Such an effect might be obscured if those who are more reckless, perhaps as a result of higher levels of testosterone, are more likely to fail when they fight. In other words, we might expect a higher variance in outcomes among people with higher levels of testosterone than among those with lower levels of testosterone. We believe that in principle this is what we see in our data. Individuals with high testosterone may be more likely to attack, but in doing so they are not more likely to win, and in fact, they may lose big.



No difference between winners and losers (Mann-Whitney U test, Z=-0.21, p=0.83).

However, there is almost a difference when looking *only* at those who won or lose when there was a war (Mann-Whitney U Test, Z=-1.85, p=0.064), see Figure 4 below. This was not significant when split by sex, possibly because it was mostly males who won wars. Males won more, but not significantly more, wars than females did, probably because males were more likely to make unprovoked attacks, which commonly resulted in instant wins.

Figure 4: Testosterone by Victory if and only if there is a war.


7
6
5
4
3
2
LNT3
763
769
79
N =
34
34
Lost
Won
WINBYWAR

Discussion and Conclusions

The findings in this study confirm several of our original hypotheses. We did find the expected negative correlation between age and testosterone. Since this was probably driven by the relatively higher number of young men and older women in the sample, it is possible that this finding is secondary to a basic sex difference, since men possessed about five times greater levels of testosterone in this sample than women, on average. This notion is supported by the finding that age did not exert a significant effect on testosterone once we controlled for gender.

Women clearly display a contrary dynamic to that of young men who appear to be more belligerent; older women are much more likely to engage in unprovoked attack than younger women. This is almost a direct linear relationship in women between age and likelihood of aggression. We suggest two interrelated reasons for this finding. First, younger women are more likely to be in the pill, thus artificially elevating their levels of estrogen. Second, older women are more likely to be menopausal, thus lowering their natural estrogen levels, while raising their relative levels of testosterone.

We find strong support for the hypothesis of a relationship between testosterone and aggressive action. In particular, high testosterone subjects are much more likely to engage in unprovoked attacks against their opponents than their lower testosterone counterparts. Similarly, we found support for our hypothesized relationship between cortisol levels and aggressive action. Subjects with lower cortisol were significantly more likely to make an unprovoked attack on their partner than higher cortisol subjects. This was not true for women, but it remained true for men.

However, we did not find our expected relationship between long-term relationships and aggressive acts. In our sample, there was no significant difference between those who were and those who were not in a long-term relationship and the propensity for unprovoked attack. This may be because the vast majority of our sample was single, thus making meaningful comparisons difficult because of a lack of sufficient variation on this independent variable. Similarly, because only two of our subjects had any children, we were unable to explore statistically the previously reported relationship between fatherhood and lowered levels of testosterone in this study (Gray et al., 2000).

One of the dynamics we explored in this paper, but which we were unable to find any support for so-called victory effects. This disconfirmed our hypothesis 5. We did, however, find some support for our hypothesis 6.These unexpected findings provide interesting grist for the theoretical mill. Clearly, male and female testosterone differs in reaction to competition. Older studies seem to suggest that male testosterone displays an expected victory effect, but more recent studies do not confirm these findings, often suggesting the reverse occurs.

In this study, testosterone remains highest, on average, just before subjects begin to play. Testosterone then dropped between the first and second sample, and then again between the second and third samples. Contrary to victory effect expectations, the final testosterone sample is much higher among those who fought and lost than among those who fought and won. However, sample sizes for both these groups is very small, eleven and six respectively, so it appears that this finding is driven by basic sex differences. In other words, because there were more men than women among the losers, low testosterone among winners may simply reflect a greater proportion of women among the winners. Overall, as might be expected, testosterone remains lower among those who choose not to fight than among those who do, but again this finding may result from sex differences in that fewer women than men choose to fight.

Several explanations for these findings, and for the contradiction with the earlier literature, seem possible. Certainly some of the reason for the earlier effects lies in the fact that all the subjects in the early studies were male, and females clearly display a divergent hormonal path with regard to the effect of competition on testosterone and cortisol. But something more subtle may be going on as well. In studies involving professional athletes or other competitors, the screening process for years prior to investigation tends to weed out players who are not as interested, not as strong, or not as motivated to win as others. In other words, the process by which a person makes it into professional competition selects for those who are relatively high in testosterone from the start. In such contexts, testosterone might easily rise and fall with victory or defeat for all the evolutionary reasons that make animals fight for dominance; they may not know why they do it, but millennia of evolution have demonstrated that dominant animals are those who have the highest likelihood of survival over the long haul, and so dominance is selected for evolutionarily. However, in a population such as that in our experiment, with random assignment, high testosterone players might easily play low testosterone players. In such a contest, even if the low testosterone player wins, through his relative reluctance to make a suicidal attack, his elevated testosterone might still not equal that of the lowered testosterone of his more belligerent partner, who started out so much higher from the outset.

The strongest and clearest finding that this study generates is that high testosterone predisposes individuals to engage in unprovoked attack against their opponents. Since testosterone is about five times higher in men, men engage in such fights more than women. And because such fights often lead to big loses, costs which all subjects are made well aware of prior to play, men tend to lose more than women. Although it should be said that big wins were possible, and did occur, through military conflict, such victories were not common.

After conducting these studies, it appears that the best analogy for the male-female divide in testosterone is that of a car. Men are accelerators and women are brakes. This is particularly true for younger member of each sex. In a contest between two accelerators with no brake, the possibility of collision remains high. In a game between two brakes, there is no accelerator to spark action, and so contact is unlikely to occur. But in a competition between a brake and an accelerator, the accelerator starts the action, and the brake will try to stop it. In other words, women will fight back exactly like men once they are provoked; they are just highly unlikely to start up the engine of conflict. But in such a competition, odds favor the brake's strength, because the accelerator will simply try to drive the car off the cliff if left to its own devices. Clearly, this biological mechanism evolved in a very different environment with very different cues and stimuli. Today, increasingly novel and complex technology, and ever more distant, both physically and psychologically, command, control and communications systems make these biological responses far more likely to wreck disaster.

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