Testosterone and Aggression in a Simulated Crisis Game

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This study investigated the impact of testosterone on aggression in a crisis simulation game. We found a significant positive relationship between levels 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. Since testosterone was around five times higher among men, and men engage in such fights more than women, there is an automatic statistical link between testosterone and aggression that is hard to separate from other possible gender-based causes.

Keywords: testosterone; experiment; aggression; crisis; gender differences

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? One of the behaviors that people have been most interested in is aggression and its many manifestations, including war. The implications of the proper origin of aggression suggest different strategies for intervention; if social conditions are responsible for violence, then changing certain situational or institutional factors 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 a catalyst 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. Critical among these factors is whether there is

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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 this experiment, we begin to test the impact of testosterone on aggressive action in a simulated crisis game.

Literature Review and Hypotheses

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 levels in women, on average. Testosterone has been shown to be stable over time within individuals but to vary with a predictable circadian rhythm, 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. 2004). More than 40 percent of the variance in individual levels of testosterone derives from heredity (Meikle et al. 1988). 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 life history appears to be with age and obesity. Other factors, including physical activity and alcohol use, do not appear related. Smoking relates to testosterone

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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 and Michalek 1998). This correlates with well-documented increases in domestic abuse during the time surrounding divorce (Mazur and Michalek 1998; Wilson and Daly 1993). Among females, by contrast, testosterone tends to *increase* with age (and estrogen *decrease*) as a result of contraceptive pill use among young women, aging processes, and menopause. As a result of these previous studies, we test the following hypotheses:

Hypothesis 1a: Younger males will have higher testosterone and show greater aggression.
Hypothesis 1b: Older females will have higher testosterone and show greater aggression.

Testosterone and aggressive action

Testosterone levels have been linked with aggression (for a review, see Meyer-Bahlberg 1981); dominance (Gray, Jackson, and McKenry 1991); antisocial behavior, including fighting, drug abuse, and nontraffic arrests (Dabbs and Morris 1990); and sensation seeking (Daitzman and 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 with dominance rank in male chimpanzees (Muller and Wrangham 2001), and heightened testosterone increases aggression in various other species (Monaghan and Glickman 1992; Svare 1983).

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Some primate models suggest two different forms of aggression, defensive and offensive. Kalin (1999) suggested that a unique neural mechanism underlies each type. He posited 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 are associated with lower levels of serotonin and cortisol and higher levels of testosterone. He argued that all forms of aggression are affected by environmental factors and, as with humans, the 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). For example, some researchers report that testosterone correlates with anger and verbal aggression in men (Von Der Phalen et al. 2002). Others find that testosterone significantly relates to levels of both verbal and physical aggression (Soler, Vinayak, and Quadagno 2000). We found that a low second-to-fourth digit ratio, which is a marker of high levels of early life testosterone exposure, predicted aggression in our war game experiments (McIntyre et al. 2007). Experimentally inducing increased testosterone levels seems to confirm these overall patterns. 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 induce noticeable increases in psychiatric symptoms, including increased manic and aggressive behaviors (Pope, Kouri, and Hudson 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 giving electric shocks to an increasingly challenging fictitious opponent (Berman, Gladue, and Taylor 1993).

Testosterone clearly has an impact in competitive settings. Male judo competitors, for example, displayed a direct relationship between levels of testosterone and the 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 suggested 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 likely to compete with others over athletics than their lower-estrogen counterparts (Cashdan 2003). This might suggest that pill use, which artificially affects 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, Walsh, and Jonik 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 and Hargrove 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 1,709 men, demonstrated a relationship between personality profiles of dominance with some aggression and elevated levels of androgens, including testosterone (Gray, Jackson, and McKenry 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, more than 85 percent of homicides were committed by men. Interestingly, more than 80 percent of the victims were also male (Daly and Wilson 1988). This pattern of vastly higher rates of same-sex male homicide seems to hold in all cultures over time (Buss and Shackelford 1997).

While it may be difficult to prove a direct relationship between testosterone and criminality, behavior that can be exacerbated by high levels of testosterone tends 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 among high-testosterone males elicit greater chances for violence to erupt. Furthermore, men convicted of domestic violence also possess higher levels of testosterone and display greater physical violence than healthy controls (George et al. 2001).

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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, and Granger 1999).

On the other hand, lower levels of testosterone correlate with self-control and social conformity (Daitzman and Zuckerman 1980). In fact, lower levels of testosterone appear to correlate with several kinds of prosocial behavior. Specifically, low-testosterone men have a more pleasant and friendly manner, including smiling more (Dabbs and Hargrove 1997), and maintain much more positive relationships with their families (Julian and McKenry 1989; Booth and 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 seventeen 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). Furthermore, 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 predisposed toward dominance and its sequelae of aggression? One explanation suggests that testosterone—while it may promote dominance—also provides some immunity against illness (Granger, Booth, and Johnson 2000). Another suggests that it might prove advantageous in combat or military conflict, enhancing the chances of winning in battle (Johnson, Wrangham, and Rosen 2002; Wrangham 1999; Johnson 2004). Buss and Shackelford (1997) argued for an evolutionary understanding of human aggression. They suggested that aggression is context-sensitive and that human males evolved to respond adaptively to different social interactions. In particular, they posited that aggression may have emerged as a solution to at least seven such problems, including stealing other's resources, defending oneself, competing with 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

Hypothesis 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.

Testosterone and relationship-status

Age is not the only factor that has been shown to exert a dramatic impact on testosterone levels. Marriage and parenthood lower testosterone 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 they examined, including body mass index, exercise, and stress, did not achieve significance. They argued that their findings support theories (Lancaster and Kaplan 1992; Wingfield et al. 1990) that 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 and 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 and 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 and 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 and Daly (1985) found that in Detroit, 73 percent of male murderers and 69 percent of male victims were unmarried, although the base rate of same-age unmarried men in Detroit at the time was 43 percent. In a larger study examining same-sex murder of unrelated people from Canada (1974–1993), England (1977–1986), Chicago (1965–1981), and Detroit (1972), Daly and Wilson (1990) again found both that murder rates drastically declined as men aged (peak murder rates in all samples were early twenties) and that married men were much less likely to commit murder than unmarried men. Divorced men, as the data from Mazur and Michalek (1998) would suggest, possess homicide rates that are most similar to single men. In another study of criminal behavior and deviance over the life cycle, Sampson and Laub (1990) found that strong marital attachments inhibited adult criminal and deviant behavior.

Therefore, we hypothesize that

Hypothesis 3: Men in long-term relationships will be less likely to engage in aggressive action than their unmarried or divorced counterparts.

Methods

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

Subjects

This study involved 186 subjects who were recruited from the Harvard Business School experimental subject pool. We were able to obtain usable testosterone samples from 180 subjects prior to the game, 78 women and 102 men. We had 134 samples from the middle round of the game, 59 women and 75 men. And we had 179 samples from the final round of the game, 77 women and 102 men. The sample sizes vary because (1) some testosterone samples did not provide valid data and (2) samples taken when the game ended before all six possible rounds had occurred were treated as final, not middle round, samples. Our sample had

TABLE 1
SUMMARY STATISTICS ON (RAW) TESTOSTERONE AND AGE

	Females					Males				
	N	Mean	*SD*	Min	Max	*N*	Mean	*SD*	Min	Max
Age	79	22.99	5.37	18	48	107	21.80	5.58	18	65
T1	78	77.72	60.29	14	323	102	341.50	202.08	45	1208
T2	59	50.19	58.56	14	304	75	241.75	140.32	28	708
T3	77	45.16	40.33	14	217	102	244.75	145.44	32	710

the following racial composition: 60.8 percent Caucasian, 19.4 percent Asian, 11.3 percent African American, 3.2 percent Hispanic, 1.1 percent Native American, and 4.3 percent Other. Ages ranged between 18 and 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 subjects were volunteers who received cash payments of either $20 or $30, depending on how well they performed during the game.

Procedure

This simulation game was complex in nature. When subjects 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 pretreated with sodium azide, an antibacterial agent. Samples were temporarily stored at room temperature, after which they were frozen, and thawed twenty-four 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, Texas). This protocol is described in detail in Gray et al. (2004). Subject samples were assigned to eight 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 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 percent, 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 that included a depression inventory; a self-esteem scale; a narcissism questionnaire; measures of stress, fear, anger; and a social dominance orientation survey. Once subjects 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, subjects 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 last 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, 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 apiece, 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 army battalions for cash or industry assets at a discounted rate of 50 percent; for example, a person who bought one battalion for $10 million 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 surrendered—an older man in the latest experiment we ran. At 8:45 p.m., it became clear that he would rather surrender, and go home, than continue to engage with an unknown 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 based on a consistent set of probabilities that depended on the balance of military power and experimental condition. After a victory, the loser lost all his battalions, and an equal amount of money (each battalion cost $10 million) was transferred from his industrial production account into that of the winner. If a player lost all of his 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 percent 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.

Each round, subjects 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 percent 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. At the end of the game, subjects found out whether they won or lost the game, after which a third saliva sample was taken (unless the game had already ended, in which case the second testosterone sample was the final one). Those who won received an additional $10 in payment (on top of the $20 earnings that all subjects received for participating 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 making and action during the game. However, 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.

Results

All raw testosterone 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 data set because it reached the maximum on the scale ($>>$ 3 *SD* above the mean) and is suspected to have been contaminated.

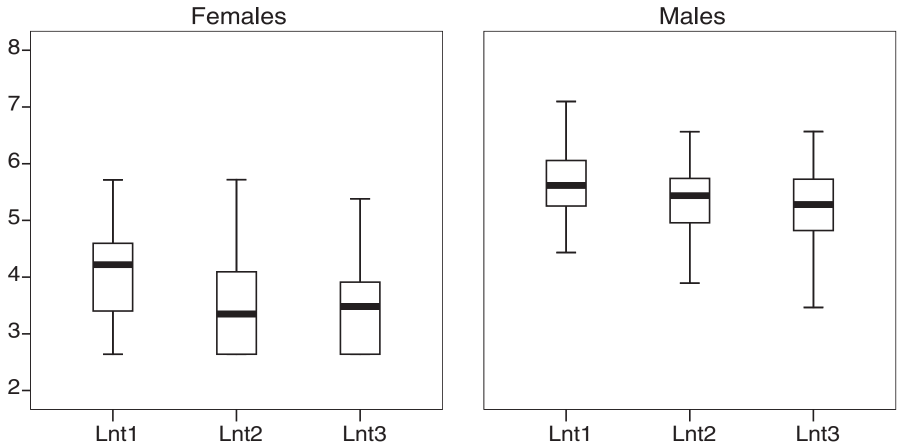
Overall testosterone levels

Figure 1 shows overall levels of testosterone in our subjects across all three samples, divided into male and female groups. There were no significant differences between the three testosterone samples (in either sex).

Testosterone and age

We found a significant negative relationship between age and all three testosterone samples (Spearman's rank correlations for lnt1, $r = -0.15$, $n = 179$, $p = .04$; lnt2, $r = -2.00$, $n = 134$, $p = .02$; lnt3, $r = -1.8$, $n = 179$, $p = .02$). However, there

FIGURE 1
LOG (LN) TESTOSTERONE LEVELS SAMPLED BEFORE (INT1), DURING (INT2), AND AFTER (INT3) THE WAR GAME



NOTE: For each sex, medians (lines), interquartile ranges (boxes), and highest and lowest values (whiskers; excluding outliers) are shown.

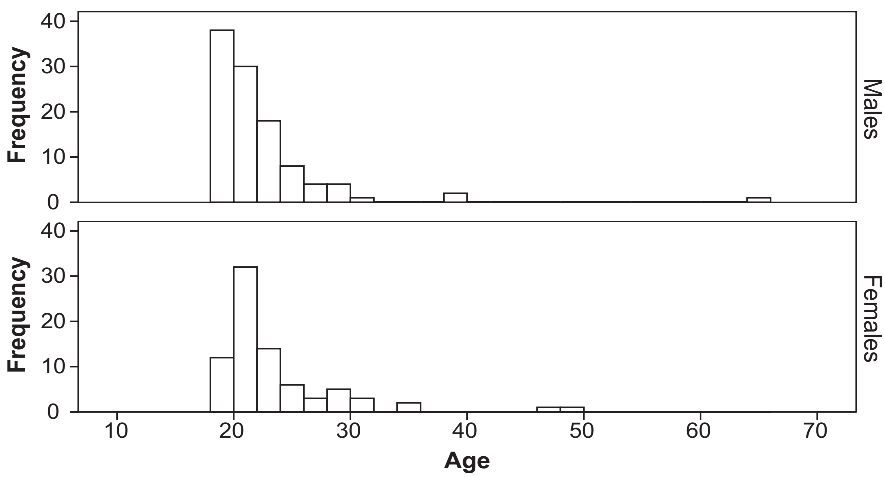
were more older women in the sample than there were older men (see histograms in Figure 2), such that a disproportionate number of young men (who typically have high testosterone levels) and a disproportionate number of older women (who typically have low testosterone levels, compared to men) may have driven these correlations (we found no within-sex correlations). These conclusions were corroborated when using a normalized age variable (given a very heavy skew in raw age data, this required transformation using the third reciprocal root: $-1/[(\text{age})^3]$). 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).

More belligerent older women

The sample size of women who attacked their opponents 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 ($Z = -2.21$, $p = .027$). This was not true for men (see Figure 3).

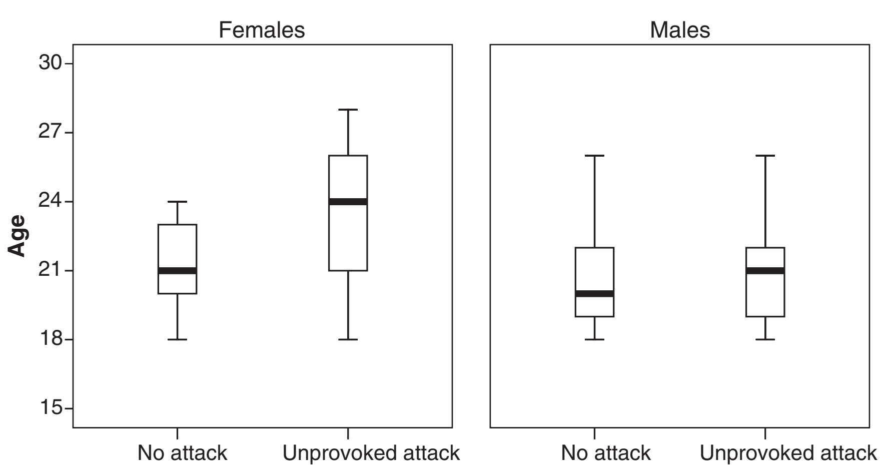
Repeating this test using normalized age and a t-test, the result is of borderline significance ($t = -1.98$, $df = 76$, $p = .051$). Older women also were more "hawkish" (meaning that they either made unprovoked attacks *or* retaliated), but this trend did not reach significance ($Z = -1.74$, $p = .08$). There was no difference at all among men (see Figure 4).

FIGURE 2
HISTOGRAM SHOWING AGES OF SUBJECTS



NOTE: There were more younger males than females in the sample, and more males overall.

FIGURE 3
OLDER FEMALES WERE SIGNIFICANTLY MORE LIKELY TO MAKE UNPROVOKED ATTACKS (NO EFFECT AMONG MALES)



Testosterone and winning

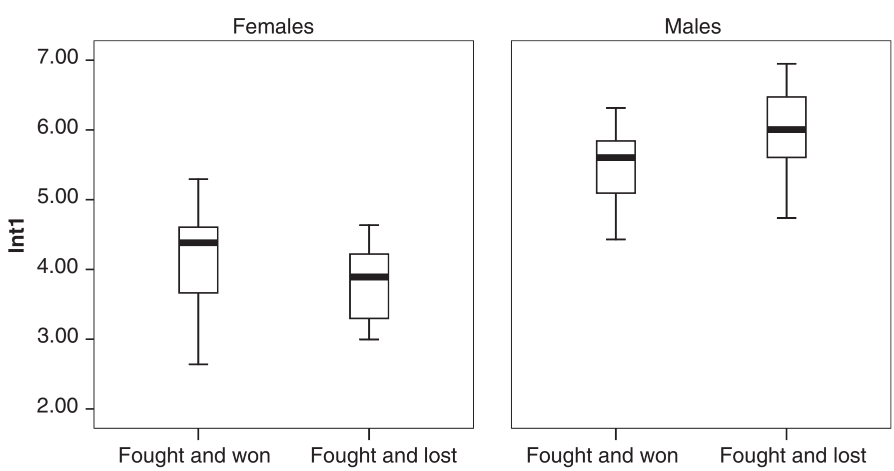
In examining the winners among those who fought, males who fought and lost had higher initial testosterone than males who fought and won ($t = -2.27$, $df = 36$, $p = .029$). There was no such effect among females (see Figure 5).

FIGURE 4

OLDER FEMALES WERE MORE LIKELY (THOUGH NOT SIGNIFICANTLY) TO MAKE UNPROVOKED ATTACKS OR RETALIATE (NO EFFECT AMONG MALES)

FIGURE 5

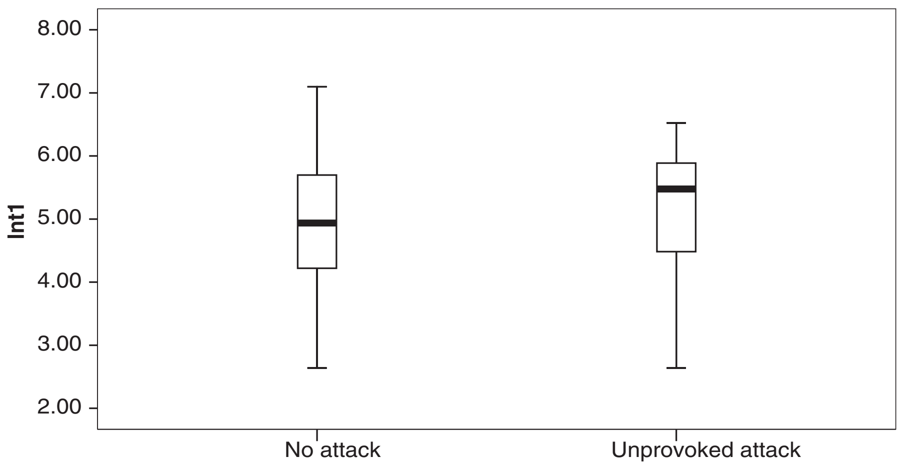
MALES WHO FOUGHT AND LOST HAD SIGNIFICANTLY HIGHER INITIAL TESTOSTERONE LEVELS THAN THOSE WHO FOUGHT AND WON (NO EFFECT AMONG FEMALES)



Testosterone and aggressive action

We used unprovoked attacks on an opponent as our dependent variable for aggression (retaliation *in response* to others' aggression may be mediated by

FIGURE 6
SUBJECTS WITH HIGHER INITIAL LEVELS OF TESTOSTERONE WERE SIGNIFICANTLY MORE LIKELY TO MAKE UNPROVOKED ATTACKS ON THEIR OPPONENTS



NOTE: There was no such effect within either sex alone, suggesting this relationship is driven by male–female differences: males have higher testosterone and attack more.

various processes and therefore implies a weaker measure of aggressive intent). Individuals with higher levels of testosterone (from the initial pregame sample) were more likely to make an unprovoked attack on their opponent (independent samples *t*-test: $t = -1.79$, $df = 152$, $p = .037$, one-tailed test; Figure 6). There were no within-sex differences in (ln) testosterone between unprovoked attackers and nonattackers (*t*-values < 0.5, $p > .6$).

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 oral contraception (the pill) among female subjects (which elevates estrogen levels). This procedure produced a model that was statistically significant in comparison to a null model containing a constant term only (chi-squared = 9.86, $df = 4$, $p = .043$; Cox and Snell *R*-squared = .062). The model correctly assigned 77.4 percent of the cases. Table 2 details the variables in the model equation and their *partial* effects (that is, their independent 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 is .324 times more likely to be an unprovoked attacker than a female. The lack of significance of these variables means they should not be overinterpreted in this model.

TABLE 2
VARIABLES IN THE LOGISTIC REGRESSION WITH UNPROVOKED ATTACK AS THE DEPENDENT VARIABLE

	B	*SE*	*p*	Exp (*B*)
LnT1	–0.295	0.304	.333	0.745
Age	0.005	0.036	.898	1.005
Gender	–1.126	0.675	.095	0.324
Pill	1.632	1.113	.143	5.112
Constant	–0.957	2.059	.642	0.384

A simple chi-square test showed that males are significantly more likely to make unprovoked attacks than females (chi-squared = 4.77, $df = 1$, $p = .029$). (Ln) testosterone was already shown above to have significant effects on unprovoked attacks.

Long-term relationships and aggressive acts

We found no relationship between subjects' type of relationship and unprovoked aggression (chi-squared tests all nonsignificant for both sexes, or when pooled). As Figure 7 shows, the proportion of unprovoked attackers was approximately equally represented in all classes of relationship (however, the sample sizes of married and cohabiting subjects were very small, so the hypothesis is hard to assess).

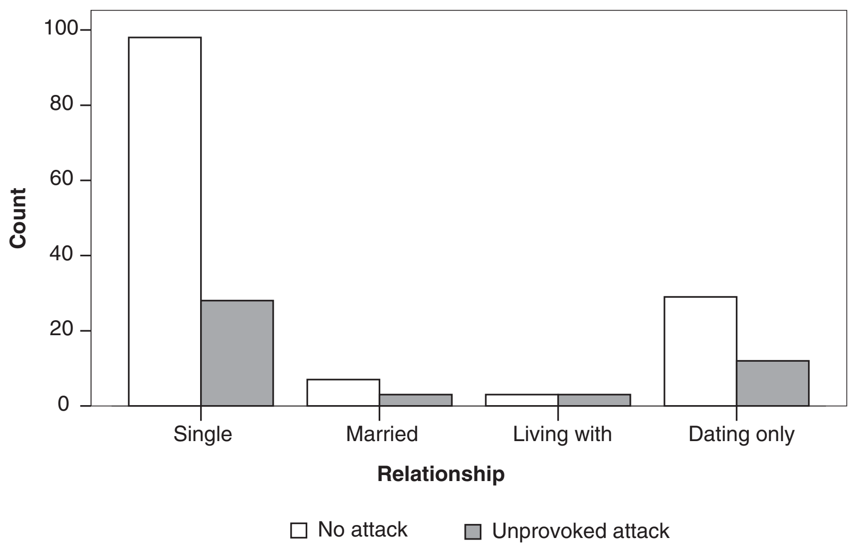
Discussion and Conclusions

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 attacks 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 on the pill, thus artificially elevating their levels of estrogen (and perhaps decreasing their competitiveness as a result). 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

FIGURE 7
THERE WAS NO SIGNIFICANT DIFFERENCE IN THE PROPORTION OF ATTACKS AND SUBJECTS' PERSONAL RELATIONSHIP STATUS



more likely to engage in unprovoked attacks against their opponents than their lower-testosterone counterparts. This result is apparently driven by the fact that males, who have much higher levels of testosterone, attacked more than females did (since we found no significant relationship between testosterone and aggression *within* either sex).

> *[H]igh-testosterone subjects are much more likely to engage in unprovoked attacks against their opponents than their lower-testosterone counterparts.*

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. 2002).

The strongest and clearest finding that this study generates is that high-testosterone individuals are more likely to engage in unprovoked attacks against their opponents. Since testosterone is about five times higher in men, and men engage in such fights more than women, there is an automatic statistical link between testosterone and aggression that is hard to separate from other possible gender-based causes. We hope to explore these links in future studies. And because such fights often lead to big losses, costs that 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 members 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 conflict is unlikely to occur. But in a competition between a brake and an accelerator, only one accelerator is needed to cause conflict: women fight back exactly like men once they are provoked. Women are just highly unlikely to start up the engine of conflict in the first place. In such a competition, the odds favor brakes over accelerators, because the latter will simply try to drive the car off the cliff if left to their own devices. Indeed, other data from this war game experiment show significant correlations between men, narcissistic personality scores, confidence of success, and making unprovoked attacks on opponents (Johnson et al. 2006). Clearly, the biological mechanisms behind aggression evolved in a very different environment to that of today, with very different cues, stimuli, and triggers. In modern political and military decision-making, 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 wreak disaster.

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