

## Hormonal Mechanisms for Regulation of Aggression in Human Coalitions

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**Abstract** Coalitions and alliances are core aspects of human behavior. All societies recognize alliances among communities, usually based in part on kinship and marriage. Aggression between groups is ubiquitous, often deadly, fueled by revenge, and can have devastating effects on general human welfare. Given its significance, it is surprising how little we know about the neurobiological and hormonal mechanisms that underpin human coalitionary behavior. Here we first briefly review a model of human coalitionary behavior based on a process of runaway social selection. We then present several exploratory analyses of neuroendocrine responses to coalitionary social events in a rural Dominican community, with the objective of understanding differences between in-group and out-group competition in adult and adolescent males. Our analyses indicate: (1) adult and adolescent males do not elevate testosterone when they defeat their friends, but they do elevate testosterone when they defeat outsiders; (2) pre-competition testosterone and cortisol levels are negatively associated with strength of coalitionary ties; and (3) adult males usually elevate testosterone when interacting with adult women who are potential mates, but in a striking reversal, they have lower testosterone if the woman is a conjugal partner of a close friend. These naturalistic studies hint that reciprocity, dampening of aggression, and competition among friends and allies may be biologically embedded in unique ways among humans.

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Once alliances start to form, there is no other reasonable strategy but to join one (Gavrilets et al. 2008:44).

No hunt needs quite so much forethought or ability to communicate complex instructions as does a war, nor do such drastic demographic consequences hinge on the outcome (Hamilton 1975:344).

Coalitions and alliances are core aspects of human sociality. Humans cooperate in a broad range of activities, including aggression and defense against other groups of humans (Carneiro 1970; Chagnon 1968, 1979a, 2012; Harcourt and de Waal 1992; Tiger 1969; Tiger and Fox 1971; Wrangham 1999). Mortality rates from intergroup conflicts in tribal societies for adult males average 10% to 30% (Beckerman et al. 2009; Chagnon et al. 1979; Ember and Ember 1997; Keeley 1996; Knauff 1991). Long-term planning for intergroup conflict and cycles of “blood revenge” are commonplace (Boehm 1984; Chagnon 1988; Gould 1999, 2000; Jacoby 1983; Otterbein 1994). Conflict among human ancestors may have a deep evolutionary history (Walker 2001; Wu et al. 2011). Surprisingly, given the key role of coalitionary behavior in human affairs, and its unique complexities, we do not know much about the neurobiological and hormonal mechanisms that facilitate and constrain cooperative in-group and out-group relationships, nor how such mechanisms develop during childhood and adolescence.

Here we first review briefly a model for the evolution of human coalitionary behavior based on a process of runaway social selection (Alexander 1971, 1974, 1990, 2012; Flinn and Alexander 2007; Gavrilets et al. 2008; Nesse 2007). We then examine possible neuroendocrine mechanisms that underpin coalitionary relationships with several empirical examples from a longitudinal study of a horticultural community on the island of Dominica. Our goal is to contribute to a Tinbergen (1963) synthesis of neuroendocrine/cognitive mechanisms, ontogeny, phylogeny, and evolutionary function of human coalitionary behavior.

## The Evolution of Human Coalitionary Behaviors

A hydrogen bomb is an example of mankind’s enormous capacity for friendly cooperation. Its construction requires an intricate network of human teams, all working with single-minded devotion toward a common goal. Let us pause and savor the glow of self-congratulation we deserve for belonging to such an intelligent and sociable species (Bigelow 1969:1).

Humans are highly prosocial; we are embedded in extensive networks of friends, family, neighbors, coworkers, acquaintances, and others (Binmore 2006; Boehm 1999; DeScioli and Kurzban 2009; Ridley 1996; Trivers 1971; Wright 1994). Empathy and morality are fundamental human traits (Alexander 1987; de Waal 2009; Fehr and Fischbacher 2003). Our treasured, seemingly benevolent

characteristics of kindness, generosity, honor, humility, and loyalty appear to have evolved, however, not as adaptations to extrinsic ecological pressures but arguably as a consequence of social dynamics generated by competition within and between groups (Alexander 1990, 2012; Bowles 2009; Choi and Bowles 2007; Flinn et al. 2005a; Frank 1995, 2003; Nesse 2007). The apparent primary purpose of human coalitions is to outcompete other human coalitions.

Evidence for the evolutionary trajectory of human family, kinship, and intergroup relations over the past one million years is indirect. We hypothesize that human cognition, extended families (with multiple generations), mating strategies, biparental care, and the capabilities for coalitionary relationships coevolved. Evidence in support of this hypothesis comes in part from (1) comparisons with extinct and extant hominoids and hunter-gatherer cultures and (2) complex neuroendocrine mechanisms that appear to mediate these unusual human traits.

### Comparisons with Extinct and Extant Primates and Hunter-Gatherer Cultures

Some components of human and chimpanzee coalitionary psychology are more likely homoplasies (independently evolved) than synapomorphies (shared derived). Body-size sexual dimorphism is an unambiguous indicator of male-male competition associated with a polygynous mating system (Alexander et al. 1979; Plavcan and van Schaik 1997) as well as the absence of significant coalitionary behavior among males (Plavcan et al. 1995). And although others may disagree (Reno et al. 2003), some australopithecine and early *Homo* ancestors were likely more sexually dimorphic than either modern humans or chimpanzees (Frayser and Wolpoff 1985; McHenry 1992; Plavcan 2012; Plavcan et al. 2005). In addition, modern humans differ from other primate species (and likely the hominid ancestors) in the relative nature and degree of stable breeding bonds, male parental investment, extended bilateral kin networks, reciprocal exogamy, and concealed ovulation, all of which may have coevolved with abilities for humans to develop intensive coalitionary behaviors (Alexander 1990; Chapais 2008; Rodseth et al. 1991).

Although humans and chimpanzees may share some general cooperative behaviors (Warneken and Tomasello 2009), human coalitionary behaviors differ significantly from those of extant great apes (Manson and Wrangham 1991; Rodseth and Wrangham 2004). Chimpanzees, for example, rarely fight group against group: border patrols usually will attack solitary individuals or small groups, not large congregations (Wrangham 1999; also see Wrangham and Glowacki 2012). Great apes do not have alliances between communities to attack/defend themselves from other (third) groups, and they do not control mating/marriage relationships with consequences for relations between kin groups.

Great apes do not appear to have any cooperative relationships with individuals outside their own group, not even with their sisters or brothers living in neighboring communities. For example, chimpanzee (*Pan troglodytes*) communities have exclusive male patrilineal lines that have not been observed to fuse or mix with male patrilineal lines from other communities (Watts et al. 2006). Brothers often help brothers in the same community (Boehm 1992), but males do not appear to help their sisters in neighboring communities (and vice versa). Bonobos also lack the distinctive human networks of intercommunity alliances based on bilateral kinship and marriage. Male

chimpanzees and bonobos share a common diffuse parental interest in juveniles in their community because paternity is obscure. Human males, in contrast, have targeted interests in their families in part because paternity is relatively certain. Human communities must therefore overcome the consequent factions between families with cooperative interfamily relations. Humans, moreover, develop cooperative intercommunity linkages involving residential reciprocity (e.g., brideservice) and complex kin lineages (e.g., Chagnon 1979b; Walker et al. 2011).

The intermediate evolutionary steps between an animal with chimpanzee-, bonobo-, or gorilla-like social structure and humans are difficult to explain (Chapais 2008, 2010, 2011; Flinn 2011; Flinn et al. 2005a, 2007; Geary 2005, 2010; Geary and Flinn 2001, 2002; Rodseth et al. 1991). The evolution of paternal care is especially problematic. Mammals that live in groups with multiple males, such as bonobos, chimpanzees, dolphins, and squirrel monkeys, usually exhibit minimal paternal care owing to uncertain paternity (Alexander 1974; Clutton-Brock 1991; Conner et al. 2001). The formation of exclusive “pair-bonds” between males and females in multiple-male groups would provide cues of nonpaternity to other males, which could facilitate infanticide by them (Hrdy 1999; cf. Borries et al. 2011; Henzi et al. 2010). Chimpanzee males, for example, do not tolerate exclusive mating relationships by other males (e.g., Muller et al. 2011; cf. Watts 1998); neither do dolphins, whose alliances are in some respects even more complex than those of great apes (Conner 2010).

In contrast, exclusive mating relationships are common among humans and are linked to fathers providing protection, information, food, and social status for their children (Gray and Anderson 2010; Hewlett 1992; Lamb 2004; Storey et al. 2000). In this respect, humans seem more similar to gorillas (*Gorilla* spp.) and gibbons (Hylobatidae) than to dolphins, chimpanzees, or bonobos (Geary and Flinn 2001). Gorillas and gibbons, however, rarely tolerate other males’ mating relationships: gorilla silverbacks usually do not reside or cooperate with other silverbacks (Watts 1996), and adult male gibbons defend exclusive territories for their families against intrusions by outside males (Palombit 1994). These obstacles suggest that gorilla or gibbon models of early human family and coalitionary behaviors are unlikely.

If human ancestors had intergroup relations similar to those of chimpanzees (see Boesch et al. 2008; Mitani et al. 2010; Watts et al. 2006; Wrangham 1999; Wrangham and Peterson 1996), it would have been difficult to make even the first steps toward cooperative alliances among males (and females) in different communities. An adult male attempting to establish a relationship with another group would likely be killed. Somehow our ancestors overcame such initial obstacles to intercommunity alliances. It is possible that our ancestors did not have hostile intergroup relations; this seems unlikely, however, on both empirical (LeBlanc 2003) and theoretical (Alexander 1990, 2012; Gavrilets and Vose 2006; Gavrilets et al. 2008; Kurzban and Neuberg 2005; Nowak 2006; Shaller and Neuberg 2008; Stevens et al. 2005; van Vugt et al. 2007; Wrangham 1999) grounds.

Recognition of kinship among individuals residing in different communities is key to intergroup cooperation. Humans are different from other hominoids in the coevolutionary development of (a) stable and moderately exclusive breeding bonds, (b) bilateral kin recognition and relationships, (c) affinal ties, and (d) reciprocity among coresident and nonresident families (Alexander 1979, 1990; Chapais 2008, 2010,

2011; Flinn 2011; Flinn and Low 1986; Flinn et al. 2007; Hrdy 2009; Muehlenbein and Flinn 2011; Quinlan 2008). The extended human family appears to be a critical building block for the evolution of more complex communities, such as the patrilocal band (Chapais 2008) and the tribe (Rodseth and Wrangham 2004), with flexible residence choice with kin in multiple communities and apparent intentional cultivation of ties with relatives in multiple locations (e.g., Hughes 1988; Marlowe 2010; Walker et al. 2010; Wiessner 2002). The cognitive and neuroendocrine mechanisms that facilitate these distinctive human traits are incompletely understood.

### Neuroendocrine Mechanisms of Coalitionary Behaviors

The neuroendocrine system is a complex set of mechanisms designed by natural selection to communicate information among cells and tissues. Steroid and peptide hormones, neurotransmitters, and other chemical messengers guide behaviors of mammals in many important ways (Ellison and Gray 2009; Henley et al. 2011; Lee et al. 2009; Ophir 2011; Ostner et al. 2011; Panksepp 2009; Young et al. 2011). An important challenge confronting human evolutionary biologists and psychologists is to understand how the neuroendocrine system has become linked with cognitive systems (e.g., Adolphs 2003a, b; Allman et al. 2011; Flinn et al. 2005b; Rilling and Sanfey 2011; Ulrich-Lai and Herman 2009) to produce the unique suite of human family and coalitionary behaviors.

Several hormones, most notably testosterone, oxytocin, and arginine vasopressin, are likely central to the development and maintenance of human male coalitions. Social effects such as victories against outsiders typically produce elevations in testosterone (Bernhardt et al. 1998; Fuxjager et al. 2009; Gleason et al. 2009; González-Bono et al. 1999; 2000; Oxford et al. 2010; Wagner et al. 2002). Like members of other taxa (Hirschenhauser and Oliveira 2006; Wingfield et al. 1990; Wobber et al. 2010), human males usually elevate testosterone in anticipation of one-on-one competitive events against other males (Gladue et al. 1989; Salvador 2005; Salvador and Costa 2009; Salvador et al. 1987). This may function to augment muscle tissue (especially upper-body strength), which itself may have been selected to facilitate the production and use of weapons to settle male-male conflicts (Bercovitch 2001). Elevated testosterone levels prior to competition may also improve coordination and cognitive performance, increase self-confidence and motivation, as well as possibly interfere with self-control (Salvador et al. 2003). The effects are not simply constrained to those directly competing, but also to those observing the competition (Bernhardt et al. 1998).

If a male is victorious in competition, his testosterone levels may increase, possibly to facilitate further successful competition in winners; if defeated, testosterone levels usually decrease, possibly to temper provocative actions of losers (Booth et al. 1989; Dabbs and Dabbs 2000; Flinn et al. 1998; González-Bono et al. 1999, 2000; Maner et al. 2008; Mazur et al. 1992; Schultheiss et al. 1999). Decreased testosterone levels would also function to prevent immunosuppression and other costs associated with otherwise elevated testosterone levels (Muehlenbein 2008; Muehlenbein et al. 2010). This would be particularly advantageous if the loser of the competition was injured.

The mechanisms by which testosterone levels change could involve acute alterations in gonadotropin-releasing hormone or luteinizing hormone, albumin or sex

hormone-binding globulin concentration (Trumble et al. 2011), tissue uptake of testosterone, conversion of hormones to or from testosterone (i.e., dehydroepiandrosterone to androstenedione to testosterone, or testosterone to estradiol), or clearance of hormones through the liver and kidneys. Two lines of evidence suggest the importance of disassociation/association between testosterone and carrier proteins or steroidogenic enzyme conversion. First, competition-associated changes in testosterone are also found in women (Bateup et al. 2002; Edwards et al. 2006; Edwards and Kurlander 2010; Kivlighan et al. 2005; Oliveira et al. 2009), suggesting that testes are not required for such changes. Second, it can take more than an hour for changes in luteinizing-hormone concentration to cause peak changes in gonadal production of testosterone in young men (Veldhuis and Iranmanesh 2004). Therefore, rapid changes in both men and women are likely the result of other mechanisms outside the hypothalamic-pituitary-gonadal axis.

Studies of testosterone response in industrialized societies have found that high levels of testosterone are associated with status seeking, antisocial behavior, and decreased generosity (Archer 2006; Zak et al. 2009), whereas low testosterone levels are often associated with affiliative behaviors. Low testosterone levels have been posited to be advantageous for group (rather than individual) competition because low testosterone could enhance cooperation among teammates by decreasing personal (selfish individual) dominance-seeking (Mehta et al. 2009). Given the importance of cooperative relationships within coalitions of humans, hormonal responses to competitive events may be contingent on whether members of the opposing team are in-group or out-group (Flinn et al. 1998; Oxford et al. 2010; Wagner et al. 2002).

Although some have suggested that the peptide hormone oxytocin underpins generalized prosocial behavior in humans (Domes et al. 2010; Kosfeld et al. 2005; Zak et al. 2005), others suggest that oxytocin motivates affiliative behavior toward specific in-group targets (de Dreu et al. 2010, 2011; Ditzen et al. 2009; Miller 2010; Shamay-Tsoory et al. 2009; Theodoridou et al. 2009) consistent with discriminative nepotism and reciprocity (Alexander 1991, 2006; Daly and Wilson 1995). Studies of effects of neurotransmitters (e.g., serotonin, dopamine) also suggest specific targeting rather than generalized altruism (Crockett 2009; Crockett et al. 2010; Tse and Bond 2002).

The biochemical mechanisms responsible for the regulation of bonds between mates, and between parents and offspring (Bartels and Zeki 2004; Bridges 2008; Carter 2002; Curtis and Wang 2003; Fisher 2002; Young and Insel 2002), also are likely involved in other types of intragroup bonding in humans. That is, the elevated arginine vasopressin, prolactin, and oxytocin that prepare males to be receptive to and care for infants (Bales et al. 2004) may be part of the neuroendocrine system that facilitates coalitionary relationships. The same might be said for the importance of the linkage between oxytocin and the dopamine D2 receptors in the nucleus accumbens responsible for positive reward in mental states (Aragona et al. 2003).

Analysis of patterns of hormone levels in naturalistic contexts can provide important insights into the evolutionary functions of the neuroendocrine mechanisms that guide human behaviors. Clinical and experimental studies may have novel or artificial conditions that potentially influence hormone responses. Naturalistic studies, on the other hand, usually cannot provide high levels of control and repeatability. In the following sections we present analyses of data on testosterone and cortisol responses

to coalitionary events from our long-term (1988 through 2011) study of a rural horticultural community on the east coast of Dominica (see Flinn 2006, 2009; Quinlan and Flinn 2005).<sup>1</sup> Our objective is to examine potential distinctive characteristics of human coalitionary behavior. We examine testosterone and cortisol responses to group competition as well as testosterone responses to potential mates. Given small sample sizes, the case examples in the following sections are intended as explorations of the diversity and nuance of hormonal responses to the complex challenges of human sociality. We challenge interested readers to comprehensively evaluate our hypotheses, and in particular to pursue research that includes measurements of oxytocin, arginine vasopressin, prolactin, and neurotransmitters, ideally in concert with information about binding at specific receptor sites.

### *The Dominoes Competition*

If androgen response to competitive outcomes influences subsequent affiliation, then elevation of testosterone is expected among members of a team that is victorious over out-group teams, but not when they defeat in-group teams (those containing their coalition partners). We speculate that elevated levels of androgens may diminish psychological states that are conducive to reconciliation (de Waal 2000) between competitors, while at the same time enhancing bonds among victorious coalition members.

In the study community of Bwa Mawego, Dominica, domino is a commonplace competitive team sport. The game is played by four players organized in teams of two against two. Although dominoes usually involves more cognitive than physical effort, players often become quite animated and evidence intense social competition, accompanied by hormonal responses. Changes in testosterone levels in response to in- versus out-group competition in dominoes were assessed from saliva samples collected from 27 healthy adult men aged 25–52 (16 pairs; 5 men were in two events, but with different conditions for in-group/out-group or win/loss; the study includes 12 men sampled in 2000 from informal tournaments previously reported in Wagner et al. 2002, and 15 additional men sampled from unarranged events in 2001–2002) the morning of, immediately before, immediately after, and 30–60 min after the end of the competition.

All domino events occurred in the afternoon or early evening (14:00–19:00); there were no apparent effects of time of collection or age of player; analyses examine changes in levels of T for each individual in response to the competitive event. For all samples, sugarfree spearmint gum was used to stimulate saliva, which was collected in a 5 ml polypropylene centrifuge tube containing sodium azide. Free testosterone was quantified via a radioimmunoassay (Coat-a-Count, Diagnostic Product Corporation) according to the manufacturer's instructions. All individual samples were run in duplicate with standards and high and low concentration controls (controls within acceptable ranges). All samples were run in a single assay, and the intra-assay coefficient of variation was less than 5%.

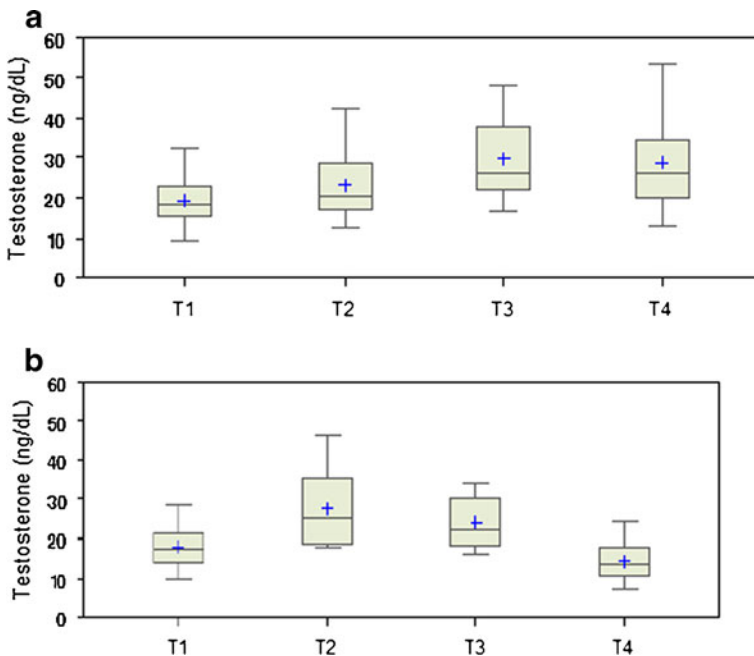
Because of the small sample size and within-subject design, changes in testosterone levels across events (pre- and post-competition) were examined by means of

<sup>1</sup> Also see supporting materials accessible online at <http://web.missouri.edu/~flinnm/>.

nonparametric Friedman and Wilcoxon signed-rank tests using proc freq in SAS. Where the Friedman statistic was significant, multiple comparison analysis with relative pairwise adjustment was used, following Siegel and Castellan 1988 (Soliani 2008). Changes in testosterone levels across events (pre- and post-competition) were examined within individuals. Further, percent change in testosterone level across events (pre- and post-competition) were examined between winners and losers with the Wilcoxon sum rank test using proc npar1way in SAS.

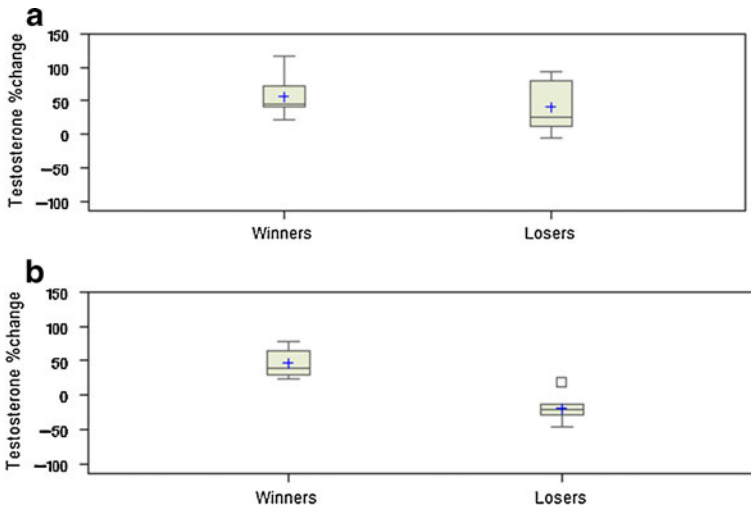
Results reveal that winning against an out-group team (not containing one's coalitionary partners) was associated with an increase in testosterone at the end of the match compared with baseline ( $Q=20.70$ ,  $N=8$ ,  $p<0.001$ ; Fig. 1a). For losers against out-group teams, testosterone levels were lower by 30–60 min post competition compared with pre-match levels ( $Q=20.50$ ,  $N=8$ ,  $p<0.001$ ; Fig. 1b). While at the end of the out-group game there were no differences in testosterone percent change between losers and winners ( $Z=1.31$ ,  $p>0.05$ ; Fig. 2a), winners had significantly higher levels of T compared with pre-match levels than did losers 30–60 min post competition ( $Z=3.30$ ,  $p<0.01$ ; Fig. 2b).

When subjects competed against teams of friends in the same tournament, there were no significant changes in testosterone levels for winners or losers (Fig. 3a and b). In addition, there were no differences in percent change in testosterone between winners and losers during the in-group competition ( $Z=0.47$ ,  $p>0.10$  and  $Z=-0.15$ ,



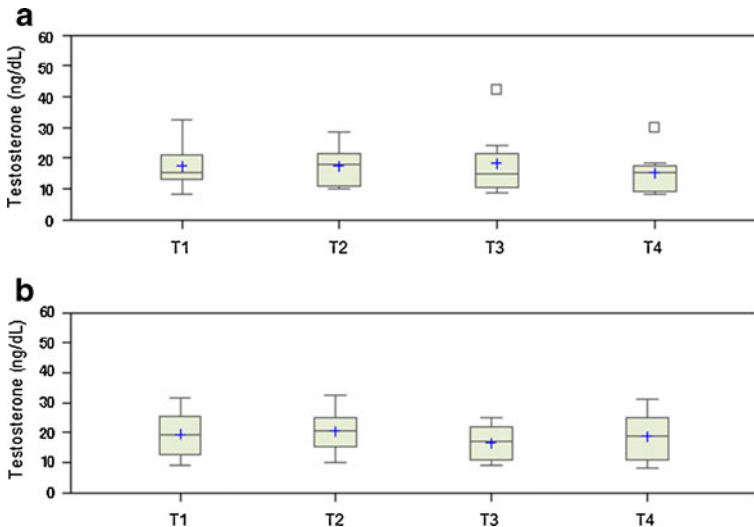
**Fig. 1** **a** Testosterone levels when victorious over an out-group team. Winning against a group of outsiders increased testosterone levels at times 3 (T3) and 4 (T4) ( $Q=20.70$ ,  $N=8$ ,  $p<0.001$ ). T1=baseline hours before competition; T2=at the beginning of the competition; T3=at the end of the competition; T4=30–60 min after the end of the competition. **b** Testosterone levels when defeated by an out-group team. Losing to a group of outsiders was associated with lowered testosterone levels immediately after and 30–60 min after competition compared to T3 but not with T1 ( $Q=20.50$ ,  $N=8$ ,  $p<0.001$ )





**Fig. 2** **a** Percent change in testosterone immediately after the out-group competition ( $Z=1.31$ ,  $p>0.05$ ). No statistical differences between winners and losers percent change in T levels right after the end of the domino competition ( $Z=1.31$ ,  $p>0.05$ ). **b** Percent change in testosterone 30–60 min after the end of the out-group competition. Winners and losers have different trajectories of T after the out-group competition. Winners have significantly increased levels of T after 30–60 min relative to losers ( $Z=3.30$ ,  $p<0.01$ ). The small squares represent the maximum observation above the 75th percentile

$p>0.10$  for T3 and T4, respectively). That is, a victory against friends does not affect testosterone significantly, whereas a victory against outsiders results in elevated testosterone. Likewise, a defeat by friends has little effect on testosterone, whereas a defeat by outsiders results in decreased testosterone from pre-competition levels.



**Fig. 3** **a** Testosterone levels when victorious over an in-group team. Winning against a group of friends does not have effects on T levels ( $Q=4.20$ ,  $N=8$ ,  $p=0.24$ ). (T1–T4 are the same as in Fig. 1a, b.) The small squares represent the maximum observation above the 75th percentile. **b** Testosterone levels when defeated by an in-group team. Losing to a group of friends does not have effects on T levels ( $Q=6.0$ ;  $N=8$ ,  $p=0.11$ ). (T1–T4 are the same as in Fig. 1a, b.)

## Cricket Matches

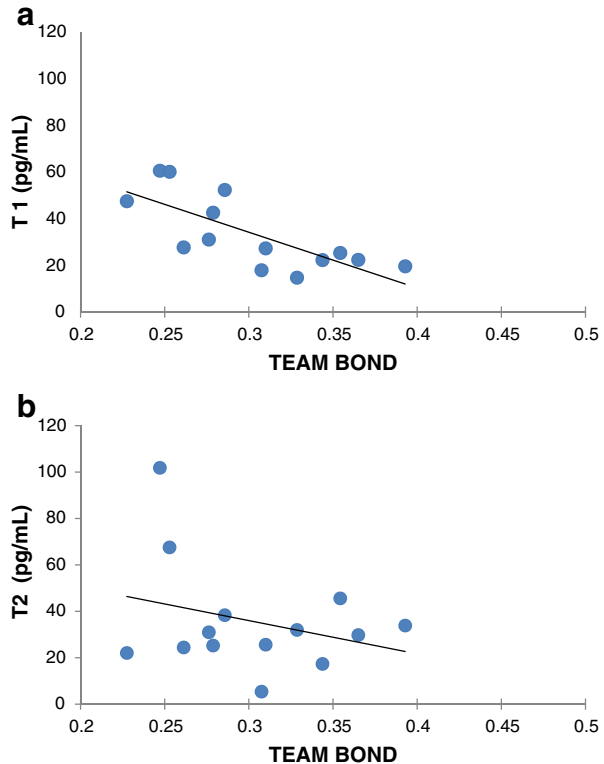
Another major venue for team competition in Bwa Mawego is the game of cricket. Children begin playing cricket at an early age with bats fashioned from palm tree fronds and using hard green fruits for balls. The rare flat plots in the otherwise rugged topography of the village are treasured as temporary cricket pitches and are often filled with neighborhood kids testing their mettle against their peers. By adolescence more structured matches occur among teams from the five major residential “hamlets” in the community that are largely kin based (for description of village geography and kinship see Quinlan and Flinn 2005). Performance in the physical and social/mental competition of cricket is often mentioned as a marker of relative status.

Percent change in salivary testosterone (post- versus pre-match) in men on a collegiate sports team has been correlated with social connectedness among teammates (i.e., those who reported higher levels of social cohesion with their teammates had larger increases in post-competition testosterone following a win) (Edwards et al. 2006). To evaluate such relationships in adolescent boys, we collected data for each player on perceived coalitionary support using a top-down successive pile sort technique (Boster 1994) during summer 2008. Nineteen teenager raters (7 from the winner team, 6 from the loser team, and 6 from the village who did not participate in the competition) were presented with 37 cards. On each card were written the first and last names of one of the 37 adolescents and young adults (ages 11 to 19 years) of the community. Each subject was asked to pile the cards based on who would support whom in case of a fight. An individual proximity matrix was built following the methods described in Anthropac for multiple sorts.<sup>2</sup> Each cell of an individual proximity matrix represents the number of times two of the 37 teenagers were placed in the same pile divided by the number of total piles the rater performed. This number represents the rater’s perceived strength of coalition support between two individuals. From each proximity matrix an aggregate matrix was built using the simple average of the 19 individual proximity matrices. Therefore each cell of the aggregate proximity matrix represents the average (from the nineteen raters) perceived strength of coalition support between two of the 37 teenagers. These procedures were performed using Ucinet 6.0 (Borgatti et al. 2002). From the aggregate proximity matrix, average strength of perceived team coalition support for each cricket player was calculated. The overall strength of team coalition support for individual  $i$  was equal to the average coalition support between  $i$  and every other teammate; we call this metric the “team bond” for individual  $i$ . Pre-match testosterone levels were highly and negatively correlated with team bond ( $\rho = -0.79$ ,  $N = 14$ ,  $p < 0.001$ ; Fig. 4a) whereas post-match levels were not ( $\rho = -0.02$ ,  $N = 14$ ,  $p > 0.10$ ; Fig. 4b).<sup>3</sup>

<sup>2</sup> Anthropac 4 reference manual available at <http://www.analytictech.com/anthropac/apacdesc.htm>.

<sup>3</sup> Saliva was collected by passive drool (via use of a straw) into a 5 ml polypropylene centrifuge tube without sodium azide. Free testosterone and cortisol were quantified via an enzyme immunoassay (Salimetrics) according to manufacturer’s instructions. All individual samples were run in duplicates with standards and high and low concentration controls (controls within acceptable ranges). All samples were run in a single assay, with the intra-assay coefficient of variation equal to 3.8% and 2.3% for testosterone and cortisol respectively. One of the players of the team that lost had undetectable levels of T (below the sensitivity of the assay) before the game. This subject was not considered for further analysis concerning testosterone.

**Fig. 4** **a** Pre-match testosterone levels and perceived coalitionary support. Pre-match T levels are associated with perceived levels of coalitionary support within own team ( $\rho=-0.77$ ,  $N=14$ ,  $p<0.01$ ). **b** Post-match testosterone levels by perceived coalitionary support. Post-match T levels and perceived levels of coalitionary support within own team ( $\rho=-0.02$ ,  $N=14$ ,  $p>0.10$ )



The relation between pre-match testosterone levels and coalitionary support from teammates is particularly interesting (cf. Kivlighan et al. 2005). Our measure of coalitionary support may indicate several potential characteristics of the subject: social dominance, social competence, prosocial and cooperative behaviors toward friends, and/or being part of a larger kin network. High ratings indicate that an individual is considered an important and valuable person in his social network. This could provide a sense of security in stressful situations, such as team competitions. A trend toward a similar and statistically significant correlation was present for pre-match cortisol levels ( $\rho=-0.43$ ,  $N=15$ ,  $p=0.10$ ). Alternatively, individuals who score higher in dominance might not perceive within-group challenges as important and hence have lower anticipatory testosterone levels.

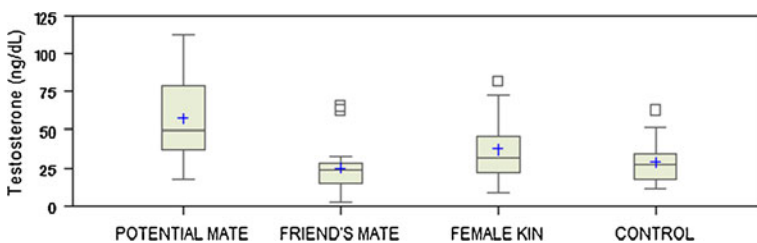
#### *Interactions with Potential Mates*

Human males, similar to other mammals (e.g., Macrides et al. 1975), often elevate testosterone when interacting with potential mates (Crews and Moore 1986; Roney 2009; Roney et al. 2003, 2007; van der Meij et al. 2008). The increase in testosterone levels can be accompanied by an increase in willingness to perform physically risky tasks in the presence of female observers (Ronay and von Hippel 2010; van der Meij et al. 2011). This physiological response of increased androgens, however, may not facilitate what we have proposed is a key component of human sociality: tolerance of other males' mating relationships (Flinn et al. 2007). Therefore we would expect

testosterone levels to be high when a male is in contact with a female who is unattached, or in a relationship with someone who is not a close friend (potential mate), but we would expect the opposite—low testosterone—when interacting with a woman who is bonded with an alliance partner. Surprisingly, this hypothesis has not been investigated previously.

Analyses of testosterone levels from afternoon (12:00–18:00) saliva samples collected during focal follows and for parents of children in our stress studies from 1994 to 1999 are consistent with this supposition: when adult males are interacting with community females, they sometimes (but not always) have elevated testosterone levels, and this change is contingent upon relationship status among the male, female, and female's mating partner. That is, testosterone levels are elevated in males when interacting with potential mates but not with female relatives or females who are in relationships (wife or coresident) with close friends (Fig. 5;  $Q=33.8$ ,  $N=18$ ,  $p<0.001$ ). Testosterone levels were examined by the nonparametric Friedman test in SAS. Where the Friedman statistic was significant, multiple comparison analysis with relative pairwise adjustment was used. Samples included in this analysis had been collected at the site of interaction (usually the woman's household; public locations such as rum shops were excluded) after at least 20 min from initial interaction, and not more than 20 min after the interaction ceased. Unfortunately because the samples were collected for other reasons and in a naturalistic context, we do not have sufficient appropriate samples from before the interactions to provide the basis for statistical evaluation of hormonal response (change in T levels from before to after the interaction). Anecdotally, some samples had been collected at various times during the morning prior to interaction events. In those few cases where multiple saliva samples had been collected from an individual on the same day, enabling comparison of before-and-after interaction levels, the direction of changes in T was consistent with the overall patterns.

These preliminary analyses are insufficient to evaluate alternative explanations of habituation, familiarity, or dominance/subordination (e.g., Bachman and Kummer 1980; Johnson et al. 2007; Oyegbile and Marler 2006). We do not have sufficient information on several important conditions: (1) testosterone levels before the interactions for many of the cases; (2) behaviors of females during the interactions (Storey et al. 2011); (3) feelings of threat or preparations for potential conflicts; and (4) prior frequency of interactions. Even with these important limitations, the apparent dampening of androgen levels when interacting with friends' mates is remarkable



**Fig. 5** Testosterone levels of adult males when interacting with females of reproductive age. Adult male testosterone levels in response to interaction with females who were resident in the community ( $Q=33.8$ ,  $N=18$ ,  $p<0.001$ ). Kin category includes five sisters, three half-sisters, three close-residence first cousins

nonetheless, and consistent with mutual respect of mating relationships and enhanced cooperation among group males.

## Conclusions

The human species has a paradoxical suite of coalitionary traits. We are capable of organizing into intensely cooperative groups for the purpose of horrific intergroup conflicts. Unlike our ape relatives, humans cultivate diverse and complex social relationships to form alliances among different communities. In band and tribal societies, we commonly arrange marriages between families in different kinship groupings and localities that may reciprocate for generations. Siblings usually maintain lifelong ties, even when residing in different communities. The neuroendocrine mechanisms that regulate such diverse and seemingly at-odds emotions and behaviors are complex and nuanced.

Our results suggest that testosterone levels during group competition are modulated depending on the relationships among the competitors: whether the opposition is friend or foe. Moreover males appear to respond differently to females contingent on whether they are bonded to a close friend. These results are suggestive of nuanced neuroendocrine mechanisms that are sensitive to social context, and that may be linked to the unique coalitionary behaviors of humans.

Testosterone may enable physiological and psychological responses for fighting or mating, but also for the comradeship among a “band of brothers.” Neuroendocrine mechanisms mediating conflicts of interest need to be regulated to maintain a cohesive social structure (e.g., Cikara et al. 2011). Hence testosterone reactivity may be modulated as a consequence of the respect for friends’ relationships. Of course testosterone interacts with other neuroendocrine mechanisms (oxytocinergic, serotonergic, etc.) in ways that likely modulate the long-term effects of the social interaction on neurobiology (cf. Aikey et al. 2002; Ferris 2008; Flinn et al. 2011; Heinrichs et al. 2009; Heinrichs and Domes 2008; Pedersen 2004). Perhaps this may all help to explain the apparent paradox of how extreme violence during intergroup competition is accompanied by extreme acts of altruism and social bonding within the group.

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