Competition, Dominance, and Social Hierarchy

Kathleen V. Casto & Pranjal H. Mehta

* Corresponding author: E-mail address: kcasto@uoregon.edu

Introduction

In ancient Egyptian society, formalized social hierarchy was manifested in the ritualistic burial of the dead. Social status was symbolized in almost every aspect of the mortuary arrangement – how close in proximity one's tomb was to the king, height from the ground, size of the tomb, level of artistic decoration, and material accoutrements (Romano, 1990; Taylor, 2001). Male members of the elite class would begin constructing a tomb at the peak of their career, even setting aside an endowment for upkeep and offerings after death (Baines & Lacovara, 2002). These preemptive structures served as status symbols for the living as the "tomb was a central vehicle for peer competition (Baines & Lacovara, 2002, p. 10)." For Egyptians, death was as important as life; it was imperative that social status attained in life be maintained in death.

Social hierarchy remains a pervasive and fundamental framework of modern human society and social relationships across cultural boundaries (Diefenbach, 2013; Sidanius & Pratto, 1999). Formalized and highly stratified hierarchies exist within political and government structures, such as traditional monarchies, dictatorships, capitalist systems, and resulting socio-economic status (SES). There are also less large-scale, yet pervasive social hierarchical systems: class or grade in school, workplace title or position, finish place in a competition, veteran or rookie status on a professional sports team, the lead versus backup role in a play or dance assemble, and even the naming system for increasingly luxurious seats on an airplane (first class, business class, and main cabin). These systematic rankings within everyday life are representative of the fundamental human need to formally classify social position based on level of distinction, wealth, talent or ability, and assumed power and privilege within each role. Some evolutionary psychologists even suggest that it was the emergence of increasingly complex social dominance interactions that provided the selection pressure for the more sophisticated human intelligence and capacity for language (Alexander, 1989; Flinn, Geary, & Ward, 2005).

Importantly, society-level social hierarchies result in stepwise differences among the upper and increasingly lower echelons (Dasgupta, 2015; Sidanius & Pratto, 1999) in access to resources directly linked to survival, such as food, water, housing, land, and healthcare (e.g., 'food deserts' common in low income neighborhoods, lack of access to potable water in certain developing nations; Montgomery & Elimelech, 2007; Walker, Keane, & Burke, 2010). In review of the adverse physiological effects of stress resulting from "dominance hierarchies" in primates, Sapolsky (2005, p. 652) states that despite the complexities of human social structure "the SES gradient of health among Westernized humans is a robust example of social inequalities predicting patterns of disease." Indeed, there appears to be a strong positive relationship in primates, including humans, between both objective and subjective social status ranking and psychological stress, health, and, ultimately, the quality of life and survivability of individuals (Demakakos et al., 2008; Sapolsky, 2004). Thus, aside from the basic science motivation to discover patterns of human behavior and related causes, there is also a perhaps more important ethical responsibility to understand the psychological and interacting biological processes involved in social dominance behavior and resulting social hierarchies.

Not all dominance-motivated social ordering is easily recognized. There are subtler hierarchies that individuals form naturally among social groups in various contexts (e.g., spontaneously emerging leader-follower relationships and popularity among peers). Everyday acts of dominance and deference (e.g., eye contact, the firmness of a handshake, the giving and taking of verbal directives) are used to attain and maintain social standing (Tiedens & Fragale, 2003). People also go to great lengths to advertise status ranking with luxury goods like clothes, shoes, jewelry, cars, and houses (a term known as conspicuous consumption; O'Cass & McEwen, 2004) – we even have objects that serve no other purpose than to advertise status (e.g. trophies, diplomas, and award ribbons). Even more subtle, social media platforms provide individuals far-reaching opportunity (70% of Americans polled used some form of social media; Pew Research Center, 2017) to attempt to out-rank their peers in quality of life, personal achievements, travel, number of friends, and perceived happiness (Chua & Chang, 2016). Though seemingly non-consequential, these small and sometimes subtle everyday gestures may serve to reinforce larger scale hierarchical social systems and represent the pervasiveness of the fundamental human striving for status.

Like other basic psychological drives, such as thirst, hunger, and sexual desire, the motivation for status has biological underpinnings in the form of a cascade of bidirectional brain-body interactions communicated via chemical messengers, specifically, steroid hormones. Testosterone was first recognized for its long-term impact on the development of male secondary sexual characteristics and sexual behavior (August, Grumbach, & Kaplan, 1972; Phoenix et al., 1959; Phoenix, Slob, & Goy; 1973). Given the more physically dominant nature of male-typical behavior in male primates, including humans, early research on social hierarchies proposed that testosterone would increase with status rank and social dominance (Ehrenkranz, Bliss, & Sheard, 1974; Purifoy & Koopmans, 1979; Rose, Bernstein, & Gordon, 1975; Sapolsky, 1982). Cortisol, well-known for its link to physical and psychological stress, was also linked in earlier research to rank within the social hierarchy (Sapolsky, 1982). Subsequent research in the decades that followed has revealed a complex relationship between testosterone, cortisol, and dominance rank and related behaviors (Casto & Edwards, 2016a; Hamilton et al., 2015; Mazur & Booth, 1998).

This chapter will review literature having to do with the social-behavioral neuroendocrinology of competition, dominance, and status hierarchies, first defining these terms and then discussing the major research findings that have emerged in this field. There is a vast research literature on these concepts pertaining to non-human animal behavior (e.g., Gleason et al., 2009); however, this chapter focuses primarily on the research involving human participants with implications for human behavior. The literature discussed here lies at the crossroads of social-personality psychology and behavioral endocrinology (two otherwise quite distinct fields), wherein the complexity of human socially-, culturally-, and contextually-embedded behavior is predicted by elegant, yet primitive, and evolutionarily adaptive hormonal fluctuations.

Defining social hierarchy, dominance, and competition.

That valuable resources (e.g., food, water, land, sexual partners) are limited stratifies social order – some (dominants/superiors) have more access to these resources than others (subordinates). Those who command these resources do so because they possess qualities that are attractive to or more dominant than others, qualities that confer greater attention, influence, or power over those that are lower-ranking (Anderson, Hildreth, Howland, 2015; Berger, Cohen, & Zelditch, 1972; 1980; Kemper, 1990). The compilation of these relationships within in social group results in *social hierarchy*, the rank ordering "of individuals or groups on a valued social dimension (Magee & Galinsky, 2008, p.354)" (as cited by Cheng et al., 2013). A higher rank order indicates that an individual or group has higher *social status* (Berger et al., 1972; 1980; Ellyson & Davidio, 1985). An individual's actual rank is not necessarily fixed – some hierarchies can be rather unstable – and is often context dependent (e.g., at work versus among peers or family). Attaining a higher position within a social hierarchy can predict increases in subsequent status-seeking behavior in an effort to maintain this high status and attain even higher positions in the future (e.g., Zilioli & Watson, 2014). Because of its notable survival advantages, direct reward value, universality, and long-term impact on psychological well-being, social status is considered a fundamental human motive (Anderson et al., 2015). Indeed, social hierarchies are a universal and evolutionarily conserved characteristic of most human societies (Chiao, 2010; Diefenbach, 2013; Gledhill, Bender, & Larsen, 1988). Additionally, neuroscientists have revealed distinct neural networks in the brain for the perception and maintenance of social hierarchy (Chiao, 2010).

Status is often decided through *competition*, "a social interaction in which access to something valued is contested between individuals and groups" (Casto & Edwards, 2016a, p. 21). The 'something valued' could be the resource that is in limited supply or the simple feeling that one possesses rank or power over others. Prevailing over one's opponent signals *dominance*, whereas failing to prevail or conceding defeat signals *deference* (Mazur, 1985). In an everyday sense, the motivation for engaging in competition may be the simple joy of winning – undoubtedly resulting from the inherent reward of status gained by the demonstration of dominance. However, the precise definition of dominance and related terms appears to depend on the specific literature within which it is discussed – social psychology, personality psychology, sociobiology, or evolutionary psychology (Cheng et al., 2013). One can possess dominance (i.e., have physical or psychological qualities that others defer to or admire, such as strength or competence), be considered dominant (i.e., rank higher), behave dominantly (e.g., verbal and nonverbal signaling of dominance, act as a leader, refusal to submit), or dominate an opponent (soundly defeat, outperform, or display considerably greater strength than an opponent) (Burgoon, Johnson, & Koch, 1998; Cheng et al., 2010, 2013, 2016; Ellyson & Davidio, 1985).

Additionally, dominance is often used to describe a general style of relating to others that expresses the explicit and implicit motivation for status and *status-seeking behavior* more broadly (Anderson & Kilduff, 2009) – a social hierarchy may be a “status hierarchy” or a “dominance hierarchy” (Chase et al., 2002; see Sapolsky, 2005; Mazur, Welker, & Peng, 2015). Figure 1 visually demonstrates the relationships between the terms competition, dominance, deference, social hierarchy, status ranking, and status-seeking behavior.

Although “dominance” is typically used as the catch-all concept for general behavior involved in the attainment and maintenance of high status, recent research has determined that there are at least two distinct, yet equally viable, cognitive and behavioral strategies for gaining influence – dominance and prestige (Cheng et al., 2010, 2013, 2014). In this view, dominance refers to a more coercive, physical or psychologically aggressive, intimidating, and conflict-based style in which an individual attains power by demanding deference. *Eminence* (Kemper, 1990) or *prestige* (Cheng et al., 2013) is a style of achieving high status through the demonstration of competence, likability, and pro-sociality and is characterized by the voluntary deference, attention, and respect of others. Given this distinction, continued research on the complexities of competition- and status-related behavior, including the underlying biological influence, will expand understanding of these important and consequential social interactions. Due to the more broad interpretation of “dominance” (meaning status-seeking behavior) in the social neuroendocrinology literature, the remainder of this chapter will operate under this generalized definition.

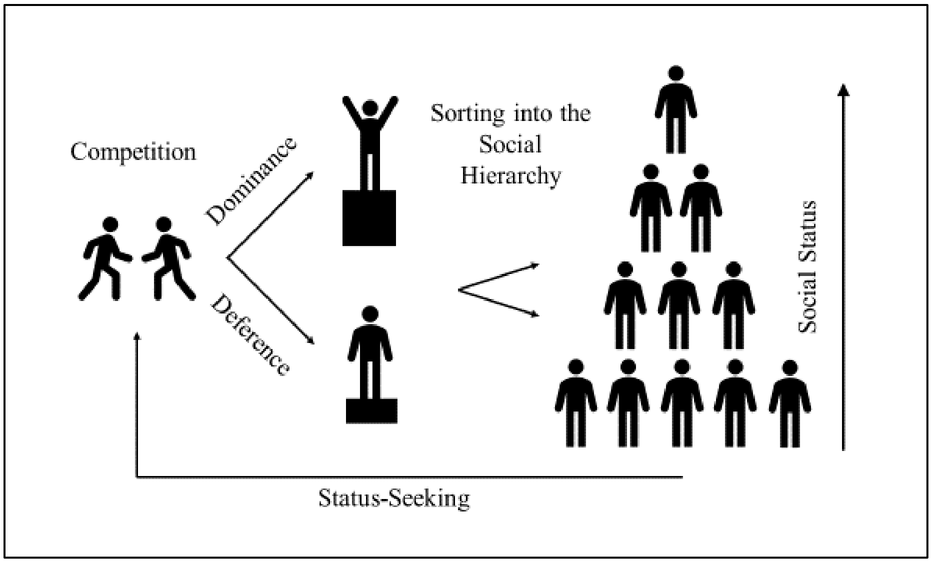

Figure 1. Visual description of terms related to status and social hierarchy.

Cortisol, stress, the social hierarchy, and competition

Cortisol is well-known for its positive relationship with stress, both psychological and physical. Acute psychological experiences of stress, particularly social-evaluative stress combined with a perceived lack of control over one's environment and outcomes, produces reliable and transient increases in cortisol (reviewed by Dickerson & Kemeny, 2004). Short-term elevations in cortisol, secreted as an end-product of the hypothalamic-pituitary-adrenal axis and via rapid and direct sympathetic stimulation of the adrenal gland (Engeland & Arnhold, 2005; Tsigos & Chrousos, 2002), provide immediate advantages for escaping or managing a stressful stimulus (e.g., mobilization and breakdown of glucose). Long-term activation or dysregulation of this system is energetically costly and can result in deleterious effects on physical and psychological health and immune system functioning (Cohen et al., 2012; McEwen, 1998; Whitworth et al., 2005) – a process known as "allostatic load" (McEwen, 1998; 2000;

2004). Thus, individual differences in basal cortisol are interpreted as a reliable predictor of allostatic load (e.g., Goyman & Wingfield, 2004).

Basal cortisol and social rank

Social hierarchy rank is thought to be inversely related to basal cortisol due to the increasing life adversity and resulting allostatic load experienced by increasingly lower ranking individuals (Knight & Mehta, 2014; Sapolsky, 2005). Early studies with non-human animals supported this notion; for example, Sapolsky (1982) showed that high-ranking males demonstrated significantly lower baseline cortisol in baboons than there more subordinate counterparts. One of the first studies in humans corroborated this finding – among a relatively small sample of male Dominican villagers, lower cortisol levels were related to higher peer ratings of likability and influence (Decker, 2000). At the society level, there is a reliable and robust negative relationship between basal cortisol levels and socio-economic status (SES; Cohen, Doyle, & Baum, 2006; reviewed by Knight & Mehta, 2014).

Recent research in humans has expanded on the cortisol-status relationship. In a relatively large sample of individuals enrolled in an executive education program, Sherman et al. (2012) showed that leaders (those responsible for managing others) had significantly lower cortisol and anxiety than non-leaders. In a follow-up study among leaders, leadership level (having and managing more subordinates and with greater authority) produced the same effect. Additionally, sense of control (generated using a measure of personal sense of power) mediated the relationship between leadership level and cortisol as well as anxiety. However, studies of collegiate athletes have shown no direct relationship between cortisol and peer ratings of leadership ability, a proxy for status (Edwards & Casto, 2013; Edwards, Wetzel, & Wyner, 2006). Using social network analysis, Kornienko et al. (2014) demonstrated that among a competitive pool of first-year nursing students, high cortisol levels were associated with low gregariousness, the number of perceived friends within the network of nursing students, but not popularity, the number of network members who perceived them as friends. In a follow-up study among members of a large mixed-sex collegiate marching band, higher basal cortisol was also related to an inability to maintain friendships within the network, i.e., greater turn-over in friendships over a two-month period (Kornienko et al., 2016).

Cortisol reactivity to a status challenge

The direction and strength of the cortisol response to stress depends on a multitude of psychological and contextual factors (Dickerson & Kemeny, 2004; Knight & Mehta, 2014; Kudielka, Hellhammer, & Wüst, 2009). Cortisol increase in response to a stressor could be considered adaptive (e.g., benefiting social status) or maladaptive (e.g., a sign of dysregulation or over-reactivity), depending on the context (e.g., competition) as well as the timing and magnitude of the response (Aschbacher et al., 2013; Shirtcliff et al., 2014).

Social rank appears to be one important factor for predicting patterns of cortisol reactivity to stress (e.g., Hellhammer et al., 1997; Sapolsky, 1982), with higher social status producing what researchers interpret as more adaptive responses, depending on the task and context (Akinola & Mendes, 2014; Shirtcliff et al., 2014). In one study, women whose cortisol levels did not habituate after repeated exposure to a stressor (i.e., a maladaptive response) subjectively rated themselves lower in SES (Adler et al., 2000). Under the condition of social-evaluative threat, men and women with high subjective social status (perceived rank among dormitory peers) showed significantly larger cortisol increases in a single session of the Trier Social Stress Test (TSST) than men and women who rated themselves low in status (Gruenewald, Kemeny, & Aziz, 2006). Cortisol increase, in this sense, could reflect a greater mobilization of energy and activity required to defend one's status when status is indeed at stake, with a non-increase in cortisol reflecting a more maladaptive (i.e., blunted) physiological response threat. However, the adaptive function of elevated cortisol would likely depend on the social context. For example, increased cortisol in response to social stressors, in some studies, appears to predict subsequent risky decision-making (van den Bos, Harteveld, & Stoop, 2009; reviewed by Starcke & Brand, 2012), a behavior that could be beneficial in contexts where risk-taking is advantageous (i.e., choosing to fight rather than flee when status is relatively high), but could be deleterious in other contexts (e.g., choosing to fight rather than flee when status is relatively low). However, there is some evidence in men and women dyads that transiently increased cortisol levels predict subsequent prosocial behaviors and cognitive states such as affiliation (in women dog-handlers, Sherman et al., 2017) and feelings of interpersonal closeness (in men participating in the TSST, Berger et al, 2016) that effectively buffer the negative psychological and physiological effects of stress (Cohen & McKay, 1984).

Situational factors also appear to moderate the relationship between status and cortisol reactivity. In at least two studies, individuals who were high on indices of dominance motivation (basal testosterone; implicit power motivation) showed greater cortisol increases across a competition for status, but only when that competition resulted in defeat (Mehta, Jones, & Josephs, 2008; Wirth, Welsh, & Schultheiss, 2006). Directly testing the moderating effects of social context on the status-cortisol reactivity relationship, Knight and Mehta (2017) manipulated both the status position and hierarchy stability of men and women competing in a mock job interview. Participants assigned to a high-status role ("manager") showed reduced cortisol reactivity and better performance compared to participants assigned to the low-status role ("builder"), but only if the assigned roles were fixed (i.e., a stable hierarchy). When told that the assigned roles could change based on performance in the interview (i.e., an unstable hierarchy), high status increased cortisol reactivity and did not result in better performance compared to low status.

In real-world athletic competition, where status is formally contested, cortisol significantly increases over the match period in men and women (e.g., Casto, Elliot, & Edwards, 2014; Edwards et al., 2006; Edwards & Kurlander, 2010; reviewed by Casto & Edwards, 2016), an effect that is likely influenced, to some degree, by the physical stress of exercise (Copeland, Consitt, & Tremblay, 2002; Tremblay, Copeland, & van Helder, 2005; Viru et al., 2010). Contrary to the above study where high rank predicted higher cortisol increase across the TSST, competition losers, a decrease in status, appear to show relatively higher increases in cortisol compared to winners (e.g., Bateup et al., 2002; Jiménez, Aguilar, & Alvero-Cruz, 2012).

Testosterone, status, and status-seeking behavior

Several decades of research have revealed a generally positive and bidirectional relationship between testosterone, social status, and status-related behavior. Initial observationally and empirically-based models of this relationship, the *Biosocial Model of Status* (Mazur, 1985) and the *Challenge Hypothesis* (Wingfield et al., 1990), have provided a theoretical basis for this research. Detailed historical accounts and extended description of these models are published elsewhere (Biosocial Model of Status: Mazur & Booth, 1998; Mazur, 2017; Challenge Hypothesis: Archer, 2006; Wingfield, 2017). The Challenge Hypothesis asserts that baseline levels of testosterone in monogamously mating birds regulate reproductive development during breeding season, increase with periods of territorial aggression under conditions of social instability (in response to male-male contests for status and sexual partners), and decrease with the expression of parental care (Wingfield, 2017). This hypothesis has been extended to humans to explain, more generally, testosterone increases in response to "competitive situations between young men" (Archer, 2006, p. 322).

The Biosocial Model of Status, initially informed by empirical studies with non-human primates and men engaged in athletic competition, proposes that stable baseline levels of testosterone predict status-related behavior. Furthermore, this model proposes that testosterone should increase in response to status gained and decrease in response to status lost. Specifically, high testosterone individuals are expected to behave more dominantly and, as a result of status gained from this dominance, demonstrate rising levels of testosterone in order to promote future competitive behavior. Likewise, low testosterone individuals are expected to behave more submissively and, as a result of status lost from this deference, demonstrate falling levels of testosterone. That is, transient shifts in testosterone represent the physiological mechanism underlying each stage of the competition, status sorting, and status-seeking processes depicted in Figure 1. Although originally thought to be an acute mechanism regulating even subtle dominance and deference signals in everyday interactions with others (Mazur, 1985), evidence of substantial testosterone fluctuations resulting from status contests may be specific to more formal competitive contexts (Mazur, Welker, & Peng, 2015).

The decades that followed the dissemination of the biosocial model for status and the challenge hypothesis have produced an abundance of empirical research testing specific predictions from these models in the context of human competition. There are several recent comprehensive reviews and meta-analyses that summarize the findings from this literature (Carré & Olmstead, 2015; Casto & Edwards, 2016a; Geniole et al., 2017; Hamilton et al., 2015; Oliveira & Oliveira, 2014). Table 1 provides a list of specific hypotheses that can be derived from the Biosocial Model of Status and Challenge Hypothesis regarding the relationships between testosterone and status ranking, status-seeking motivation, and status-seeking behavior. Some of these hypotheses have been tested empirically more than others (e.g., #1 and #2 more than #5). Among the specific hypotheses that have been well-tested, nearly all of them have been supported by some studies, but also not supported by others (#1- Burnham, 2007; Cashdan, 2003; Dabbs & Morris, 1990; Josephs et al., 2006; Mehta et al., 2017; Tremblay et al., 1998; van Bokhoven et al., 2006; Wirth & Schultheiss, 2007; #2 - Carré et al., 2009; Grant & France, 2001; Schultheiss, 2007; Sellers, Mehl, & Josephs, 2007; Welker & Carré, 2015; #3 - Cashdan, 1995; Purifoy & Koopmans, 1979; Zyphur et al., 2009; Apicella et al., 2014; Bateup et al., 2002; #4 - Carré et al., 2013; Costa & Salvador, 2012; Jiménez et al 2012; Norman et al., 2015; #5 - Peters et al., 2016; #6 - Apicella et al., 2014; Carré & McCormick, 2008; Casto & Edwards, 2016b; Casto et al., 2014; Edwards et al., 2006; Guezennec et al. 1995; Steiner et al., 2010; van der Meij et al., 2010; #7 – Schultheiss, Campbell, McClelland, 1999; Schultheiss & Rohde, 2002; Schultheiss et al., 2005; #8 - Bos et al., 2012; Carré, Baird-Rowe, & Hariri, 2014; Carré & McCormick, 2008; Hermans, Ramsey, & van Honk, 2008; Mehta & Josephs, 2006; Mehta et al., 2015a; Welling et al., 2016). To clarify general concepts that have emerged from the research testing these hypotheses, we summarize the three main empirically-supported predictions from this literature below.

Table 1.

Hypotheses derived from the Biosocial Model for Status and the Challenge Hypothesis
1) High T individuals behave more dominantly than low T individuals; Low T individuals behave more submissively
2) High T individuals are high in dominance motivation (dominant personality, motivated for status); Low T individuals are low in dominance motivation
3) Individuals with high status have higher T than individuals with relatively lower status
4) Winning a competition increases T; Losing a competition decreases T
5) Behaving dominantly increases T; Behaving submissively decreases T

6)	Engaging in a competition (a threat/challenge to status) increases T
7)	Individuals high in dominant personality/motivation for status show increases in T across a competition; Individuals low in dominant personality/motivation for status show decreases in T across a competition
8)	Increased T promotes an increase in subsequent status-seeking behavior or cognitive states that would benefit social status-seeking

1) Prediction #1: Basal testosterone is related to status-motivated and dominance behavior.

One of the original and more simplistic predictions of the Biosocial Model of Status is that individuals in high status positions in a social hierarchy would have relatively higher baseline testosterone levels. Higher testosterone would not only motivate behaviors to achieve such a high-status position, but also increase further as a result of its attainment. Although some earlier research supported this prediction in humans and other species (Dabbs & Morris, 1990; Purifoy & Koopmans, 1979; Sapolsky, 1982), subsequent research has shown that hierarchical social ranks such as socio-economic status and peer-rated ranking are not directly related to testosterone levels in men and women (Cashdan, 1995; Edwards et al., 2006; Mehta & Josephs, 2010; earlier work reviewed by Mazur & Booth, 1998; Newman, Sellers, & Josephs, 2005). However, those who want status may not always have it, and the complexities (e.g., context-dependence) of a social hierarchy may make it difficult to directly link social status and absolute testosterone levels. Indeed, a recent study of male employees working for corporate businesses revealed that testosterone levels among these men were positively related to self-reported authoritarian leadership style, but only for those who were not in management (leadership) positions (van der Meij. Schaveling, & van Vugt, 2016). Consistent with meta-analytic data on the relationship between actual leadership position and testosterone (van der Meij et al., 2016), managers did not have higher testosterone levels on average than their subordinate workers. Rather than directly predicting status position, basal testosterone appears to predict how individuals respond to shifts in status. That is, high testosterone individuals respond negatively (e.g., poorer performance on a spatial or verbal test) to a drop in status, whereas low testosterone individuals respond neutrally or negatively to a rise in status (Josephs et al., 2003, 2006; Mehta et al., 2008; Newman et al., 2005).

Due to the complexities of achieving high status or leadership positions, basal testosterone may better predict personality characteristics and behaviors motivated towards achieving status (whether or not those efforts are successful). Indeed, basal testosterone is considered an important "personality variable," that predicts dominance behaviors in various contexts (Newman & Josephs, 2009; Sellers, Mehl, & Josephs, 2007; Mehta et al., 2008). In competition, testosterone levels have been positively related to perceptions of one's personal success (Casto, Rivell, & Edwards. 2017), competitive decision-making and subsequent task confidence (Eisenegger et al., 2017, but see Apicella et al., 2011), and competitive task persistence (Welker & Carré, 2015). However, testosterone has been found to be negatively related to the ability to accurately judge the thoughts and feelings of others (empathic accuracy) in laboratory and real-world settings, an aspect of cognition that may have negative consequences on other's perceptions of one's leadership ability (Ronay & Carney, 2013). A recent study employing an economic decision-making task in which dyadic status relationships are determined during play (dominant-submissive, dominant-dominant, and submissive-submissive; the hawk-dove game) showed that baseline testosterone was positively correlated to taking a dominant position (Mehta et al., 2017). Although there are mixed reports on the direct relationship between testosterone and self-reported dominance (e.g., Cobey et al., 2015; Grant & France, 2001; Neave et al., 2003), trait dominance has emerged as an important moderator of testosterone's relationship to dominant, competitive, or aggressive behavior (Mehta et al., 2015a;

for review, Carré & Archer, 2017). For example, in one study of men competing for the affection of a woman, high testosterone individuals displayed more dominant behaviors, but the relationship was specific to those who self-identified as dominant (Slatcher, Mehta, & Josephs, 2011). Furthermore, the relationship between testosterone and social status or dominance behaviors appears to also be moderated by basal levels of cortisol (see below section on the *Dual-hormone Hypothesis*).

2) Prediction #2: Testosterone levels are transiently altered during contests for status, more often in the positive direction for winners than losers.

A second main prediction of the Biosocial Model of Status is that gaining status through winning a dominance contest should increase testosterone levels from baseline, whereas losing should decrease testosterone levels (i.e., the *winner-loser effect*, also referred to as the *winner effect*; reviewed by Casto & Edwards, 2016a). Support for this prediction has been found in studies of laboratory competition, where testosterone levels increased across competition for those who won, but decreased for those who lost (e.g., Apicella et al., 2014; Carré et al., 2013; Costa & Salvador, 2012; Norman et al., 2015). However, other studies have found that testosterone increases across competition regardless of the outcome (Carré & McCormick, 2008; Henry et al., 2017; Steiner et al., 2010; van der Meij et al., 2010). Summarizing the extant literature on the winner-loser effect, Carré and Olmstead (2015) concluded that a number of studies have reported that male winners had elevated testosterone levels relative to losers, but that a nearly equal number of studies have failed to find such an effect. For women, less studied in general, the proportion of studies that show null findings is even greater (Carré & Olmstead, 2015). However, a recent meta-analysis of 60 effect sizes on the winner-loser effect (Geniole et al., 2017) determined that winners do in fact show an increase in testosterone compared to losers, who on average experience no change in testosterone. Although the effect was not moderated by sex, the effect was only significant in men (men Cohen's d = .23; women d = .14).

However, the winner-loser effect in this meta-analysis appears to depend on important contextual factors; average effect sizes were moderately large only when the studies were conducted in non-laboratory testing locations (e.g., athletic competitions), when the outcome (win or loss) was determined naturally (not contrived or manipulated), when the competition duration was greater than 15 minutes, and when the pre-competition saliva sample was taken more than 10 minutes before competition (Geniole et al., 2017). Even though each of these moderators independently accounted for effect size differences in the winner-loser effect, they are not mutually exclusive factors; studies of the hormonal response to naturally-occurring athletic competition are always outside the laboratory, where the competition outcome cannot be manipulated, and usually last longer than 15 minutes. Thus, the winner-loser effect is less well-supported in experimental designs outside of formal athletic competition. As a matter of convenience and limited access to athletes immediately prior to and following a match, participants in studies of athletic competition are often asked to give their pre-competition sample more than 10 minutes before the match begins and more than 10 minutes after the competition has ended (e.g., Jiménez et al., 2012). These studies have been more likely to show dramatic win-loss differences in testosterone change. For studies that acquired samples immediately prior to and following competition (mostly with women athletes), testosterone increases significantly across the competition period regardless of outcome (e.g., Casto et al., 2014; Casto & Edwards, 2016b; Casto et al., 2017; Edwards et al., 2006; Edwards & Kurlander, 2010).

The issue of lab versus non-lab competition in determining the emergence of the winner-loser effect is currently unresolved. What the laboratory context gains in experimental control, it perhaps loses in being able to sufficiently activate competitive motivation and in being able to create a more realistic social setting where actual status is at stake. What field studies gain in ecological validity, they lose in experimental control. One of the most important potential confounds in the hormonal response to athletic competition is physical exertion, a factor that can elevate testosterone levels independent of competition and the psychological experience of gaining or losing social status (Copeland et al., 2002; Tremblay et al., 2005; Viru et al., 2010). However, efforts to quantify physical exertion in studies of the testosterone response to athletic competition (e.g., blood lactate, number of minutes played, self-reported physical exertion, observer-rated physical exertion) have not found any significant correlations between these metrics of exertion and T (Aguilar et al., 2013; Casto and Edwards, 2016b; Oliveira et al., 2009; Suay et al., 1999). Furthermore, one of us (KVC) has recently collected saliva samples from trained men and women rifle shooters competing in intra- and inter-squad rifle competition, a sport that requires the athletes remain as still as possible. As with other sporting competitions that require more movement, rifle competition results in significant elevations in testosterone on average and for the majority of the athletes sampled over the course of competition (+6-41% change, Casto & Edwards, unpublished).

3) Prediction #3: Transient increases in testosterone (associated with a status challenge) promote future or subsequent status-seeking behavior.

More recently, researchers have begun to explore the functional significance of transient increases in testosterone, i.e., the adaptive consequence on subsequent cognition and behavior (for initial review, see Carré, McCormick, & Hariri, 2011). If, in fact, testosterone increases in some individuals and under certain contexts, does this change serve a beneficial purpose for attaining or maintaining status in the future? The desire to compete again may reflect elevated dominance motivation when the individual has the potential to improve status rank (i.e., when the potential benefits outweigh the risks). In men, increases in testosterone during competition predict the subsequent decision to compete again against the same opponent in losers (Mehta & Josephs, 2006) and aggressive individuals (Carré & McCormick, 2008), or a different opponent in decisive winners (Mehta et al., 2015b).

Testosterone increase during competition may also predict subsequent aggressive behavior in men (Carré et al., 2009), an effect that appears to be moderated by trait anxiety (Norman et al., 2015). Also in men, testosterone increases associated with monetary wins and losses relate to future financially risky choices (Apicella et al., 2014). Increased testosterone has also been related to a more positive subsequent performance in athletic contexts (Cook & Crewther 2012a, 2012b). In one study of women soccer players, the higher an athlete's testosterone remained within the 30 minutes after competition, the greater her willingness to reconcile with her opponent – a prosocial strategy for status maintenance (Casto & Edwards, 2016c). Extending beyond correlational evidence, studies of exogenously administered testosterone have shown that, for periods of time up to 4 hours after administration, participants administered testosterone demonstrate altered cognitions and behaviors that may promote status-seeking or aid in status maintenance in competitive contexts (e.g., Bos et al., 2010; Eisenegger et al., 2010; Hermans et al., 2006; Mehta et al., 2015a; Radke et al., 2015; van Honk et al., 2012; reviewed by Eisenegger et al., 2011). For example, a series of studies by van Honk and colleagues suggests that testosterone administration, after a several hours, increases threat vigilance and reduces fear-potentiated startle, responses that are matched, in some cases, with activation of brain areas associated with emotional reactivity (Hermans et al., 2006; Hermans, Ramsey, van Honk, 2008; van Honk et al., 1999; for review, Carré & Olmstead, 2015). Testosterone administration also may reduce cognitive reflection in men (Nave et al., 2017) and behaviors thought to reflect empathy in women (Hermans et al. 2006; van Honk and Schutter 2007; van Honk et al. 2011; Wright et al., 2012). Additionally, other research has shown that after receiving a dose of exogenous testosterone, men appear to perceive themselves as more physically dominant (Welling et al., 2016).

Testosterone and cortisol interact to predict social status: The Dual-hormone Hypothesis

Early predictions that testosterone should directly and positively predict social status have failed to garner unanimous empirical support (e.g., Neave et al., 2003; review by Mazur & Booth, 1998; Mehta & Josephs, 2010). Evidence that cortisol inhibits, suppresses, or otherwise antagonizes testosterone secretion and action at target tissues (Burnstein et al., 1995; Chen et al., 1997; Johnson et al., 1992) combined with initial behavioral evidence that these two hormones might interact to predict aggression (Dabbs, Jurkovic, & Frady, 1991; Popma et al., 2007), suggests that a more integrative approach to the hormone-social status relationship was necessary. Following these early indications, Mehta and Josephs (2010) proposed that "only at low levels of cortisol should higher testosterone encourage higher status (p.898)" – a statement that serves as the basis of the *dual-hormone hypothesis*. Testing this hypothesis, Mehta and Josephs (2010) indeed showed that only if an individual was relatively low in cortisol did testosterone positively relate to dominance behaviors when instructed to act as a leader (Study 1, in men and women) and when deciding to compete again following a defeat in a rigged puzzle competition (Study 2, in men).

Several novel replications of the dual-hormone effect have been published (for an earlier review, see Mehta & Prasad, 2015). In varsity women athletes, Edwards and Casto (2013) showed that testosterone positively related to actual status as ranked by teammates, but only at relatively low levels of cortisol. As with the original studies conducted by Mehta and Josephs, the relationship trended towards an inverse relationship between testosterone and status for those with high levels of cortisol. In a sample of male business executives, testosterone positively predicted the number of subordinates over which an executive had authority (but not income or education level) only if the individual had relatively low cortisol (Sherman et al., 2016). Using social network analysis, Ponzi et al. (2016) showed that among professional male rugby players, participants with low cortisol (but not those with high cortisol) demonstrated higher network centrality (a proxy for social status) in measures of "betweenness" and popularity. Recently published research has even extended the dual-hormone hypothesis to collective hormone profiles in groups. Akinola et al. (2016) measured basal testosterone and cortisol in a large sample of MBA students organized into (diverse and mixed-sex) groups of three to six members and asked to compete against other groups in a business-related decision-making task. Collectively high testosterone was significantly and positively related to group performance, but only if that group had relatively low collective cortisol. Although null findings are less likely to be published, there have been other studies that have also failed to support the dual-hormone hypothesis (e.g., Geniole et al., 2013; Mehta et al., 2017).

A high-testosterone/low-cortisol profile has also been found to relate to antisocial attitudes (Sollberger, Bernauer, & Ehlert, 2016) and externalizing psychopathology in adolescents (Tackett et al., 2014), factors that would seem to be detrimental to social status in modern society. However, other studies have shown that a high-testosterone/high-cortisol profile (the inverse of the original dual-hormone effect) predicts deviant or psychopathic traits (Welker et al., 2014), reactive aggression, and self-reported feelings of dominance (Denson, Mehta, & Ho Tan, 2013). However, at least one study has shown that the interaction between testosterone and cortisol has no relationship to antisocial, socially deviant behavior in a large sample (4,462) of male U.S. Army veterans (Mazur & Booth, 2014).

How a high-testosterone/low-cortisol individual (or group) behaves in everyday interactions with others to result in higher status is not yet fully understood. This hormone profile may manifest in a style of interacting that balances a desire for status with a desire to affiliate and promote social bonding among others in the group or network. Or, these individuals could have a personality that balances status and power motivation with relaxed confidence and low-anxiety – a personality profile that is likable, and therefore more likely to garner the support of others required to attain and maintain status. Perhaps high-testosterone/high-cortisol individuals interact with others with high anxiety, low confidence, aggression, or desperation, effectively thwarting attempts to actually achieve status. Future research should explore, more in-depth, personality correlates and behavioral interaction-styles of high-testosterone/low-cortisol and high-testosterone/high-cortisol individuals. It is also possible that the mechanism explaining the dual-hormone effect is an interaction between the negative effects of chronically elevated cortisol and physiological processes involved in testosterone’s ability to drive status-seeking behavior. That is, perhaps allostatic-load-related stress and resulting high basal cortisol dampens or inhibits mechanisms for status motivation and related behaviors (i.e., a high testosterone-status relationship). Future research should expand the theoretical basis and practical applications of the dual-hormone hypothesis. Additionally, although this hypothesis originally concerned the interaction between basal testosterone and basal cortisol, how testosterone and cortisol changes interact to predict status and performance-related behavior (e.g., Mehta et al., 2015b) is a topic of interest for future research.

Moderators of the relationships between competition and testosterone

Recent research has exposed increasingly complex qualifiers, moderators, and extenuating circumstances that impact both the effect of competition on testosterone change and the effect of testosterone change on subsequent behavior. These moderating variables fall under two broad categories: (1) *person* and (2) *context* factors (reviewed by Casto & Edwards, 2016a; Hamilton et al., 2015, Oliveira and Oliveira, 2014, Salvador & Costa, 2009). Table 2 provides a categorical list of the person and context factors that have been studied and appear to be important for influencing either the relationship between basal testosterone and dominance behavior, the testosterone response to competition, or the effect of testosterone change on subsequent status-seeking behavior.

Table 2. *Potential moderators of the relationship testosterone and status or dominance*

Person	**Context**
Physiological	*Performance-related*
Basal Cortisol[1]	Win/Loss[14]
2D:4D digit ratio[2]	
Sex[3]	*Status-relations*
	History of wins and losses against same opponent[15]
Personality traits	
Implicit Power Motivation[4]	Closeness or decisiveness of win/loss[16]
Dominance[5]	
Aggressiveness[6]	*Situational aspects of competition design*
Competitiveness[7]	Intra- or inter-group nature of a competition[17]
Social anxiety[8]	
Self-construal[9]	Group versus individual-based competition[18]
Psychological/Cognitive states	Outcome is determined by chance or ability[19]
Mood[10]	

Task-related self-efficacy[11] Cognitive appraisal of performance or opponent[12] Task enjoyment[13]	*Geographical/territorial* Home versus away location of competition[20]

**Table references: 1) Edwards & Casto, 2013; Mehta & Josephs, 2010; Ponzi et al., 2016; Sherman et al., 2016; Wu et al., 2017. 2) van Honk et al., 2012. 3) Carré et al., 2013. 4) Schultheiss & Rohde, 2002; Schultheiss et al., 2005. 5) Mehta et al., 2015a. 6) Carré & McCormick, 2008. 7) Costa & Salvador, 2012. 8) Maner et al., 2008; Norman et al., 2015. 9) Welker et al., 2017. 10) Mazur & Lamb, 1980; Mehta & Josephs, 2006; Mazur et al., 1997; Zilioli & Watson, 2013. 11) Costa, Serrano, & Salvador, 2016; Salvador & Costa, 2009. 12) Casto et al., 2017; Gonzalez-Bono et al., 1999; Oliveira et al. 2014. 13) Mehta et al., 2015b. 14) Apicella et al., 2014; Carré et al., 2013; Costa & Salvador, 2012; Jiménez et al., 2012; Norman et al., 2015; Zilioli & Watson, 2014. 15) Zilioli & Watson, 2014. 16) Mehta et al., 2015b; Zilioli, Mehta, & Watson, 2014. 17) Oxford, Ponzi, & Geary, 2010; Wagner, Flinn, & England, 2002. 18) Mehta, Wuehrmann, & Josephs, 2009. 19) van Anders & Watson, 2007. 20) Carré, 2009; Carré et al., 2006; Neave & Wolfson, 2003.

Early studies of the testosterone response to competition included mood as an additional variable based on the notion that testosterone should increase when dominance is achieved through winning, but only if the individual experienced high positive emotions regarding the win (Gladue et al., 1989; Mazur & Lamb, 1980; McCaul, Gladue, & Joppa, 1992; Mazur, Susman, & Edelbrock, 1997). In the first study published on the testosterone response to status-enhancement and competition in humans, Mazur and Lamb (1980) stated that, "when a man achieves a rise in status through his own efforts, and he has an elation of mood over the achievement, then he is likely to have a rise in testosterone" (p. 236). Although subsequent research has shown the importance of mood as an intervening factor (Mehta & Josephs, 2006; Zilioli & Watson, 2013), state-level mood may serve only as a proxy for a more important personality factor: dominance motivation. Arguably, only those who have a strong motivation for dominance would experience elation upon achieving it through competition. Indeed, Schultheiss et al. (1999) wrote that, "It would seem reasonable to assume that personality factors may moderate individuals' testosterone responses to succeeding or failing at a dominance contest" (p. 234).

Implicit power motivation is the degree with which an individual derives reward from "having physical, and mental or emotional impact" on others (Stanton & Schultheiss, 2009, p. 942). Those higher in implicit power motivation tend to be more likely to show an increase in testosterone (and cortisol) in response to competition, particularly under the context of a win (Schultheiss & Rohde; 2002; Schultheiss et al., 1999, 2005; Wirth et al., 2006). However, this relationship appears to depend on sex – with stronger, more consistent relationships found for men than for women (Stanton & Schultheiss, 2007). Although implicit power motivation has received the most empirical attention, self-reported *trait dominance* (e.g., Carré et al., 2009; Mehta et al., 2015a) and *competitiveness* (Casto, 2016; Costa & Salvador, 2012) may also play an equally important role in regulating testosterone-status relationships and testosterone response to competition. In Mehta et al. (2015a), testosterone administration in women resulted in increased competitive decision-making (i.e., a greater percentage of the trials in which the competitor chose to compete again afterwards), but only if the participant scored high on a personality measure of dominance motivation and, also, won the competition. For participants that lost the competition, testosterone administration decreased competitive decision-making regardless of individual differences in dominance motivation.

Social context also moderates the relationship between testosterone and competitive performance. In one of the first demonstrations of this, Newman et al. (2005) showed that high testosterone individuals placed in a high-status position performed well on a spatial and verbal task, but high testosterone individuals placed in a low-status position performed poorly in comparison. This effect, dubbed the *mismatch effect* (Josephs et al., 2006), explains how situational constraints that contrast with self-perceptions hamper status-seeking efforts or competitive performance when status is threatened. The mismatch effect is also relevant for group-level performance. Among college students assigned to work in a group on class assignments for an entire semester, the greater the mismatch between testosterone and status rank within the group (i.e., the more negative the relationship), the lower the group's collective self-efficacy (i.e., the lower their shared confidence in ability to succeed), a measure that is indicative of group functioning and performance (Zyphur et al., 2009).

Another social context factor that could affect that relationship between testosterone and status is hierarchy stability, the degree with which one's status could readily be changed. Zilioli, Mehta, and Watson (2014) proposed that under conditions of status instability there should be a reversal of the winner-loser effect, whereby winners should decrease in testosterone and losers should increase. This amendment to the Biosocial Model of Status, termed the *Status Instability Hypothesis*, is based on the notion that if the function of a testosterone increase is to promote future status-seeking behavior, then winners who just barely won should be *less* motivated to compete again because of a high chance of moving down in status. However, losers who just barely lost should be *more* motivated to compete again because of a high change of moving up in status. Testing this hypothesis with women, Zilioli et al. (2014) showed that women competing in a number tracing task who won by only a small margin (given feedback of their narrow win throughout multiple trials in the task) decreased in testosterone from before to after the task, whereas women who lost by a narrow margin slightly increased in testosterone (Study 1). In a second companion study, under conditions of relative performance uncertainty, women competing in Tetris showed greater competition-related declines in testosterone than women who lost (Study 2). A simultaneous study in men competing in Tetris on two consecutive days (Zilioli & Watson, 2014) found evidence that day-two testosterone increased significantly more across the competition period for those whose status reversed from the day-one competition (i.e., a day-one win followed by a day-two loss, or vice versa; an unstable hierarchy) compared to men who won both days or lost both days (a stable hierarchy). When wins and losses where manipulated to be either "clear" or "narrow," Wu et al. (2017) showed that testosterone levels decreased significantly for narrow winners, but only if their basal cortisol levels were relatively high. Despite some empirical support in these studies for the Status Instability Hypothesis with regards to the direction of testosterone change, no studies have demonstrated the reverse win-lose effect pattern consistent with this hypothesis and have also shown that this pattern of testosterone changes predicts subsequent motivation to compete again – a main tenet of the hypothesis. To make more informed inferences about the functional significance of testosterone increases and decreases resulting from status gained and lost within stable and unstable social hierarchies, future research should attempt to corroborate testosterone reactivity with post-contest motivational states related to social status.

The wide array of moderating factors complicates attempts to understand relationships between hormones and competition, but is rightly indicative of the complexity of human nature and the intricate social context of status-striving. Figure 2 displays an updated theoretical framework for future studies testing both basal and dynamic testosterone-status relationships. For a more complete understanding of the role of person and context factors, future research will require relatively large sample sizes to properly test moderation and other complex interactions.

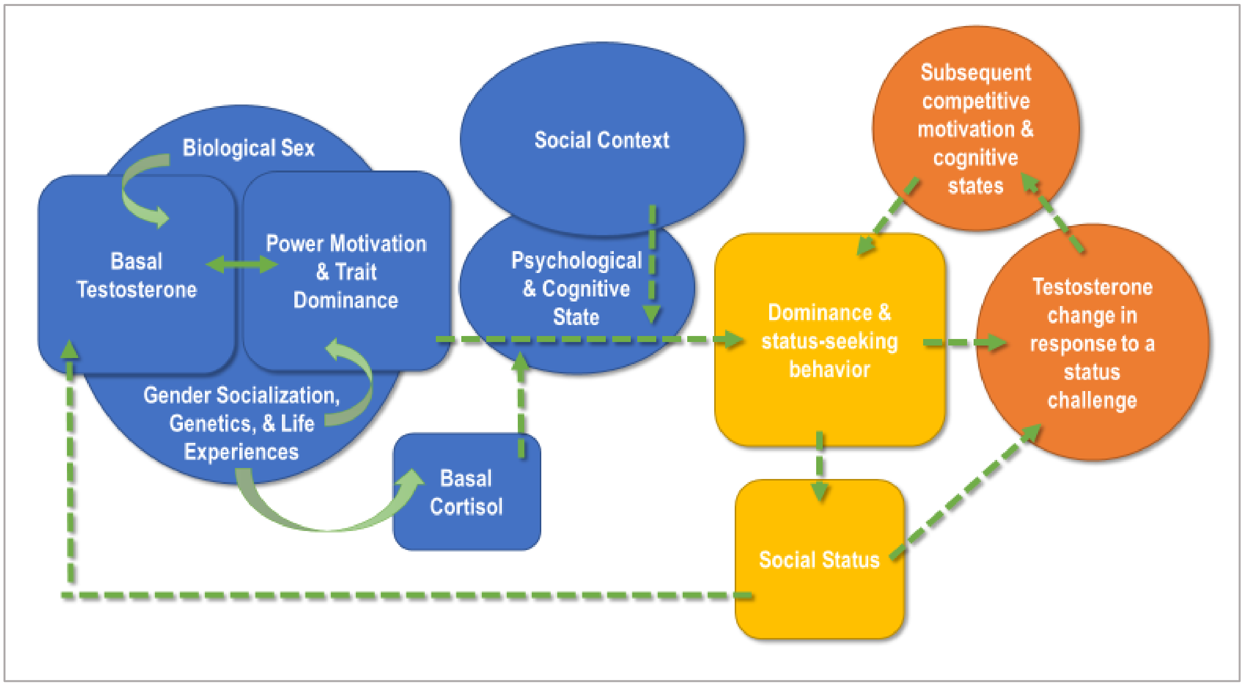

Figure 2. Theoretical model for the testosterone-social status relationship

Additional future directions

The field of social-behavioral neuroendocrinology is a burgeoning area of scientific inquiry. Although the last three decades have produced foundational discoveries, there are many unanswered questions and new directions for future research.

The role of trait competitiveness in predicting testosterone response to competition

According to *Social Comparison Theory*, the drive to compete is derived from the basic human need to reduce uncertainty between one's own performance and the performance of others in order to maintain superior relative position (Festinger, 1954; Garcia, Tor, & Schiff, 2013). For some, this drive is sufficiently strong to prompt greater efforts to engage and succeed in situations where relative judgments about performance are made. Because comparison to others through competition is how relative social status is determined, individual differences in competitiveness, the "desire to win in interpersonal situations" (Smither & Houston, 1992, p.408), may be a direct predictor of relative social status or the motivation to acquire it. Given the apparent connection between status-seeking and testosterone, competition-related changes in testosterone levels may depend on individual differences in trait competitiveness. Welker and Carré (2015) recently reported that basal testosterone in men correlates with persistence in attempting to solve puzzles made intentionally unsolvable by the experimenters. Although conceptually different than competitiveness *per se*, task persistence is a core quality of highly competitive individuals. Future research should consider including competitiveness as a person factor regulating hormonal response to competition and explore conceptual and statistical relationships between competitiveness and trait dominance, as well as power motivation.

Group dynamics and social network analysis

Real-world and everyday contests for social status occur in the context of complex social networks involving multilayered social group interactions with others. Despite the importance of group dynamics in status attainment and maintenance, previous research on the social neuroendocrinology of dominance has largely focused on the individual – testing participants in solitary rooms with little to no interaction with their "opponent." It's reasonable to assume that status lost or gained in contexts where participants have no current or future potential interaction with each other would have, at best, minor impact on one's physiology or behavior, i.e., relative standing to an unknown person may have little relevance to perceptions of social status. Indeed, individuals who are more characteristically similar and closer in a social network typically have amplified social comparison and competitiveness with each other (e.g., sibling rivalry; Garcia et al., 2013). Thus, behaviors driven by status motivation are most effectively employed when relevant to others in a social group, one that the individual identifies with. Recognizing the role of group processes and social influence on competitive efforts and hormonal responses will be important for a comprehensive understanding of the social neuroendocrinology of competition. Status motivation and underlying hormonal correlates should be considered within the context of social groups (e.g., Oxford et al., 2010) with reference to factors such as an individuals' level of group identification, status ranking within the group, inter- and intra- group competition, and need for affiliation. Social neuroendocrinologists could consider implementing group social psychology techniques (e.g., Cheng et al., 2010, 2013; Ronay et al. 2012) to explore relationships among group members and group-level interactional characteristics of social hierarchies. Advanced statistical techniques could also prove helpful in implementing more comprehensive social group dynamics (e.g., social network analysis; Kornienko et al., 2014; 2016).

The functional significance of transient elevations in testosterone

Another fruitful area of future research involves increasing our understanding of the adaptive purpose of testosterone reactivity in status-relevant. Thus, it is important to expand research on the immediate and subsequent benefits of rapid and transient elevations in testosterone during competitive behavior and as a result of status shifts. As discussed above, previous research has shown that testosterone elevations, under certain contexts, increase subsequent willingness to compete again and appear to alter cognitions in ways that could benefit status-seeking. Going further, researchers could explore testosterone-related competitive decision making when manipulating aspects about one’s opponent (e.g., photos of potential opponents could be shown with aspects such as gender, dominance-related facial features, and information about that opponent’s skill level and history of success in competition could be manipulated). Another area of interest involves moving beyond just the categorical choice of willingness to compete again or not and devising a quantifiable measure of competitive effort following testosterone elevation (i.e., a subsequent task of competitive persistence). As researchers expand the post-competition repertoire of status-related behaviors, both antisocial and prosocial means of status maintenance should be considered, as these are opposing yet equally viable strategies (Cheng et al., 2013). It is also important to understand the potential benefit of testosterone change, in relation to both physiology and psychology, with the purpose of expanding the relevance, reach, and applicability of social neuroendocrinology more generally. That short-term testosterone elevations can advantageously alter future behaviors and cognitions suggests that there could be some marketable use in developing evidenced-based interventions, tasks that could reliably produce endogenous testosterone increases in contexts where this response could prove beneficial for performance. Researchers in other fields, policy makers, and organizations interested in how social groups function (e.g., corporate business and sports teams) would better understand the value of implementing social neuroendocrinology methods with proper tools for taking advantage of the testosterone-status relationship.

Other areas of future research

Other future directions include pursuing a better understanding of hormonal modulation of reward circuitry in the brain (e.g., Bless et al., 1997; Frye et al., 2002; Hermans et al., 2010; Montoya et al., 2014; Packard, Cornell, Gerianne, 1997; Salvador & Costa, 2009). Although researchers have a growing understanding of how testosterone and other sex steroids relate to behavior, less is known about the neural mechanisms of this relationship. Additionally, social neuroendocrinology, discipline-wide, is challenged with the vital goal of improving assay methodologies to increase the validity of hormone measurement (Granger et al., 2004; Granger et al. 2007; Welker et al., 2016). Perhaps there is no more pressing task than this given that the accuracy of hormone data is the basis of all other assumptions about hormone-behavior relationships. Finally, future research should make greater efforts to explore how the research discussed in this chapter is dependent on sex, gender, gender identity, and gender socialization and expand theoretical models to include a more comprehensive understanding of the endocrinology of status motivation and social hierarchies among women (Casto & Prasad, 2017).

Concluding remarks

Competition, dominance, and social hierarchy are aspects of human behavior, past and present, that represent a fundamental human need to attain and maintain social status. The core of these behaviors is driven and can be explained by complex endocrinological processes interacting with the social environment. Understanding these relationships helps explain the causes and consequences of social stratification – why, for example, those born in conditions of poverty face harsher realities, have more barriers to educational achievement, job advancement, and healthcare. Recognizing how our biology influences the struggle to have and be more than others at the society-level, and the individual differences of this drive, is perhaps one vital step in altering perceptions and creating greater awareness for the disparate situations of others. Through the lens of individual and group functioning and performance, there is also great opportunity. Seeking out the best of human potential, hormonal-status relationships can be used to discover interventions beneficial to performance in competitive tasks and functioning within social networks.

References

Adler, N.E., Epel, E.S., Castellazzo, G., & Ickovics, J.R. (2000). Relationship of subjective and objective social status with psychological and physiological functioning: Preliminary data in healthy white women. *Health Psychology*, *19*, 586-592.

Aguilar, R., Jiménez, M., & Alvero-Cruz, J. R. (2013). Testosterone, cortisol and anxiety in elite field hockey players. *Physiology & Behavior*, *119*, 38-42.

Akinola, M., & Mendes, W.B. (2014). It's good to be king: Neurobiological benefits of higher social standing. *Social Psychological and Personality Science*, *5*, 43-51.

Akinola, M., Page-Gould, E., Mehta, P.H., & Lu, J.G. (2016). Collective hormonal profiles predict group performance. *Proceedings of the National Academy of Sciences*, *113*, 9774-9779.

Alexander, R.D. (1989). Evolution of the human psyche. In P. Mellars, C. Stringer (Eds.), *The human revolution: Behavioural and biological perspectives on the origins of modern humans* (pp. 455–513). Princeton: Princeton University Press.

Anderson, C., Hildreth, J.A.D., Howland, L. (2015). Is the desire for status a fundamental human motive? A review of the empirical literature. *Psychological Bulletin*, *141*, 574-601.

Anderson, C., & Kilduff, G.J. (2009). The pursuit of status in social groups. *Current Directions in Psychological Science*, *18*, 295-298.

Apicella, C.L., Dreber, A., Gray, P.B., Hoffman, M., Little, A.C., & Campbell, B. C. (2011). Androgens and competitiveness in men. *Journal of Neuroscience, Psychology, and Econonmics*, *1*, 54-62.

Apicella, C.L., Dreber, A., & Mollerstrom, J. (2014). Salivary testosterone change following monetary wins and losses predicts future financial risk-taking. *Psychoneuroendocrinology*, *39*, 58-64.

Archer, J. (2006). Testosterone and human aggression: an evaluation of the challenge hypothesis. *Neuroscience & Biobehavioral Reviews*, *30*, 319-345.

Aschbacher, K., O'Donovan, A., Wolkowitz, O.M., Dhabhar, F.S., Su, Y., & Epel, E. (2013). Good stress, bad stress and oxidative stress: insights from anticipatory cortisol reactivity. *Psychoneuroendocrinology*, *38*, 1698-1708.

August, G.P., Grumbach, M.M., & Kaplan, S.L. (1972). Hormonal changes in puberty: III. Correlation of plasma testosterone, LH, FSH, testicular size, and bone age with male pubertal development. *Journal of Clinical Endocrinology & Metabolism*, *34*, 319-326.

Baines, J., & Lacovara, P. (2002). Burial of the dead in ancient Egyptian society. *Journal of Social Archaeology*, *2*, 5-36.

Bateup, H.S., Booth, A., Shirtcliff, E.A., & Granger, D.A. (2002). Testosterone, cortisol, and women's competition. *Evolution and Human Behavior*, *23*, 181-192.

Berger, J., Cohen, B. P., & Zelditch, M. (1972). Status characteristics and social interaction. *American Sociological Review*, *37*, 241–255.

Berger, J., Heinrichs, M., von Dawans, B., Way, B. M., & Chen, F. S. (2016). Cortisol modulates men's affiliative responses to acute social stress. *Psychoneuroendocrinology*, *63*, 1-9.

Berger, J., Rosenholtz, S. J., & Zelditch, M. (1980). Status organizing processes. *Annual Review of Sociology*, *6*, 479–508.

Bless, E.P., McGinnis, K.A., Mitchell, A.L., Hartwell, A., & Mitchell, J.B. (1997). The effects of gonadal steroids on brain stimulation reward in female rats. *Behavioral Brain Research*, *82*, 235-244.

Bos, P. A., Hermans, E. J., Ramsey, N. F., & Van Honk, J. (2012). The neural mechanisms by which testosterone acts on interpersonal trust. *NeuroImage*, *61*(3), 730-737.

Burgoon, J. K., Johnson, M. L., & Koch, P. T. (1998). The nature and measurement of interpersonal dominance. *Communications Monographs*, *65*, 308-335.

Burnham, T. (2007). High-testosterone men reject low ultimatum game offers. *Proceedings of the Royal Society B*, *274*, 2327-2330.

Burnstein, K., Maiorino, C., Dai, J., & Cameron, D., (1995). Androgen and glucocorticoid regulation of androgen receptor cDNA expression. *Molecular and Cellular Endocrinology*, *115*, 177–186.

Carré, J. (2009). No place like home: testosterone responses to victory depend on game location. *American Journal of Human Biology*, *21*, 392-394.

Carré, J.M., & Archer, J. (2017). Testosterone and Human Behavior: The role of individual and contextual variables. *Current Opinion in Psychology, 19*, 149-153.

Carré, J.M., Baird-Rowe, C., & Hariri, A.R. (2014). Testosterone responses to competition predict decreased trust ratings of emotionally neutral faces. *Psychoneuroendocrinology*, *49*, 79-83.

Carré, J.M., Campbell, J.A., Lozoya, E., Goetz, S.M., & Welker, K.M. (2013). Changes in testosterone mediate the effect of winning on subsequent aggressive behaviour. *Psychoneuroendocrinology*, *38*, 2034-2041.

Carré, J.M., Gilchrist, J.D., Morrissey, M.D., & McCormick, C.M. (2010). Motivational and situational factors and the relationship between testosterone dynamics and human aggression during competition. *Biological Psychology*, *84*, 346-353.

Carré, J.M., McCormick, C.M & Hariri A.R. (2011). The social neuroendocrinology of human aggression. *Psychoneuroendocrinology*, *36*, 935-944.

Carré, J.M., & Olmstead, N.A. (2015). Social neuroendocrinology of human aggression: Examining the role of competition-induced testosterone dynamics. *Neuroscience, 286,* 171-186.

Carré, J.M., & McCormick, C.M. (2008). Aggressive behavior and change in salivary testosterone concentrations predict willingness to engage in a competitive task. *Hormones and Behavior, 54*, 403-409.

Carré, J.M., McCormick, C.M., & Hariri A.R. (2011). The social neuroendocrinology of human aggression. *Psychoneuroendocrinology*, *36*, 935-944.

Carré, J., Muir, C., Belanger, J., & Putnam, S. K. (2006). Pre-competition hormonal and psychological levels of elite hockey players: relationship to the 'home advantage'. *Physiology & Behavior*, *89*, 392-398.

Carré, J.M., Putnam, S.K., & McCormick, C.M. (2009). Testosterone responses to competition predict future aggressive behavior at a cost to reward in men. *Psychoneuroendocrinology*, *34*, 561-570.

Cashdan, E. (1995). Hormones, sex, and status in women. *Hormones and Behavior*, *29*, 354-366.

Cashdan, E. (2003). Hormones and competitive aggression in women. *Aggressive Behavior*, *29*, 107-115.

Casto, K.V. (2016). The role of status motivation and social context in predicting competitive will and hormonal response to competition (Doctoral dissertation). Retrieved from ProQuest and Emory University's Electronic Thesis and Dissertation Repository, http://pid.emory.edu/ark:/25593/rrqrg.

Casto, K.V., & Edwards, D.A. (2016a). Testosterone, cortisol, and human competition. *Hormones and Behavior*, *82*, 21-37.

Casto, K.V., & Edwards, D.A., (2016b). Before, during, and after: How phases of competition differentially affect testosterone, cortisol, and estradiol levels in women athletes. *Adaptive Human Behavior and Physiology*, *2*, 11-25.

Casto, K.V., & Edwards, D.A. (2016c). Testosterone and reconciliation among women: After-competition testosterone predicts prosocial attitudes towards opponents. *Adaptive Human Behavior and Physiology*, *2*, 220-233.

Casto, K.V., Elliott, C.M., & Edwards, D.A. (2014). Intercollegiate cross country competition: Effects of warm-up and racing on salivary levels of cortisol and testosterone. *International Journal of Exercise Science*, *7*, 318-328.

Casto, K.V., & Prasad, S. (2017). Commentary to the special issue, Hormones and Human Competition: Recommendations for the study of women and sex effects in hormones and competition research. *Hormones and Behavior*, *92*, 190-194.

Casto, K.V., Rivell, & Edwards, D.A. (2017). Competition-related testosterone, cortisol, and perceived personal success in recreational women athletes. *Hormones and Behavior*, 92, 29-36.

Chase, I.D., Tovey, C., Spangler-Martin, D., & Manfredonia, M. (2002). Individual differences versus social dynamics in the formation of animal dominance hierarchies. *Proceedings of the National Academy of Sciences*, *99*, 5744-5749.

Chen, S., Wang, J., Yu, G., Liu, W., & Pearce, D. (1997). Androgen and glucocorticoid receptor heterodimer formation. A possible mechanism for mutual inhibition of transcriptional activity. *Journal of Biological Chemistry*, *272*, 14087–14092.

Cheng, J.T., & Tracy, J.L. (2014). Toward a unified science of hierarchy: Dominance and prestige are two fundamental pathways to human social rank. In *The psychology of social status* (pp. 3-27). Springer New York.

Cheng, J.T., Tracy, J.L., Foulsham, T., Kingstone, A., & Henrich, J. (2013). Two ways to the top: Evidence that dominance and prestige are distinct yet viable avenues to social rank and influence. *Journal of Personality and Social Psychology*, *104*, 103-125.

Cheng, J.T., Tracy, J.L., & Henrich, J. (2010). Pride, personality, and the evolutionary foundations of human social status. *Evolution and Human Behavior*, *31*, 334-347.

Cheng, J.T., Tracy, J., Ho, S., & Henrich, J. (2016). Listen, follow me: Dynamic vocal signals of dominance predict emergent social rank in humans. *Journal of Experimental Psychology*, *145*, 536-547.

Chiao, J.Y. (2010). Neural basis of social status hierarchy across species. *Current Opinion in Neurobiology*, *20*, 803-809.

Chua, T.H.H., & Chang, L. (2016). Follow me and like my beautiful selfies: Singapore teenage girls' engagement in self-presentation and peer comparison on social media. *Computers in Human Behavior*, *55*, 190-197.

Cobey, K.D., Nicholls, M., Leongómez, J.D., & Roberts, S.C. (2015). Self-reported dominance in women: Associations with hormonal contraceptive use, relationship status, and testosterone. *Adaptive Human Behavior and Physiology*, *1*, 449-459.

Cohen, S., Doyle, W.J., Baum, A. (2006). Socieconomic status is associated with stress hormones. *Psychosomatic Medicine*, *68*, 414-420.

Cohen, S., Janicki-Deverts, D., Doyle, W.J., Miller, G.E., Frank, E., Rabin, B.S., Turner, R.B. (2012). Chronic stress, glucocorticoid receptor resistance, inflammation, and disease risk. *Proceedings of the National Academy of Sciences*, *109*, 5995-5999.

Cohen, S., & McKay, G. (1984). Social support, stress, and the buffering hypothesis: A theoretical analysis. In A. Baum, S.E. Taylor, & J.E. Singer (Eds.), *Handbook of psychology and health* (pp. 253-267). Hillsdale, NJ: Erlbaum.

Cook, C.J., & Crewther, B.T. (2012a). Changes in salivary testosterone concentrations and subsequent voluntary squat performance following the presentation of short video clips. *Hormones and Behavior*, *61*, 17-22.

Cook, C.J., & Crewther, B.T. (2012b). The effects of different pre-game motivational interventions on athlete free hormonal state and subsequent performance in professional rugby union matches. *Physiology & Behavior*, *106*, 683-688.

Copeland, J.L., Consitt, L.A., & Tremblay, M.S. (2002). Hormonal responses to endurance and resistance exercise in females aged 19-69 years. *The Journals of Gerontology. Series A, Biological and Medical Sciences*, *57*, 158-165.

Costa, R., Serrano, M. A., & Salvador, A. (2016). Importance of self-efficacy in psychoendocrine responses to competition and performance in women. *Psicothema*, *28*, 66-70.

Costa, R., & Salvador, A. (2012). Associations between success and failure in a face-to-face competition and psychobiological parameters in young women. *Psychoneuroendocrinology*, *37*, 1780-1790.

Dabbs, J. M., Jurkovic, G. J., & Frady, R. L. (1991). Salivary testosterone and cortisol among late adolescent male offenders. *Journal of Abnormal Child Psychology*, *19*, 469-478.

Dabbs, J.M., & Morris, R. (1990). Testosterone, social class, and antisocial behavior in a sample of 4,462 men. *Psychological Science, 1*, 209-211.

Dasgupta, K. (2015). *Introducing social stratification: The causes and consequences of inequality*. Boulder, CO: Lynne Rienner Publishers Inc.

Decker, S.A. (2000). Salivary cortisol and social status among Dominican men. *Hormones and Behavior*, *38*, 29-38.

Demakakos, P., Nazroo, J., Breeze, E., & Marmot, M. (2008). Socioeconomic status and health: The role of subjective social status. *Social Science & Medicine*, *67*, 330-340.

Denson, T.F., Mehta, P.H., & Tan, D.H. (2013). Endogenous testosterone and cortisol jointly influence reactive aggression in women. *Psychoneuroendocrinology*, *38*, 416-424.

Dickerson, S.S., & Kemeny, M.E. (2004). Acute stressors and cortisol responses: A theoretical integration and synthesis of laboratory research. *Psychological Bulletin*, *130*, 355-391.

Diefenbach, T. (2013). *Hierarchy and organization: Toward a general theory of hierarchical social systems*. New York: Routledge.

Edwards, D.A., & Casto, K.V. (2013). Women's intercollegiate athletic competition: Cortisol, testosterone, and the dual-hormone hypothesis as it relates to status among teammates. *Hormones and Behavior*, *64*, 153-160.

Edwards, D.A., & Kurlander, L.S. (2010). Women's intercollegiate volleyball and tennis: Effects of warm-up, competition, and practice on saliva levels of cortisol and testosterone. *Hormones and Behavior*, *58,* 606-613.

Edwards, D.A., Wetzel, K., & Wyner, D.R. (2006). Intercollegiate soccer: saliva cortisol and testosterone are elevated during competition, and testosterone is related to status and social connectedness with teammates. *Physiology and Behavior*, *87,*135-143.

Ehrenkranz, J., Bliss, E., & Sheard, M.H. (1974). Plasma testosterone: correlation with aggressive behavior and social dominance in men. *Psychosomatic Medicine*, *36*, 469-475.

Eisenegger, C., Haushofer, J., & Fehr, E. (2011). The role of testosterone in social interaction. *Trends in Cognitive Sciences*, *15,* 263-271.

Eisenegger, C., Kumsta, R., Naef, M., Gromoll, J., & Heinrichs, M. (2017). Testosterone and androgen receptor gene polymorphism are associated with confidence and competitiveness in men. *Hormones and Behavior*, *92,* 93-102.

Eisenegger, C., Naef, M., Snozzi, R., Heinrichs, M., & Fehr, E. (2010). Prejudice and truth about the effect of testosterone on human bargaining behaviour. *Nature*, *463*, 356-359.

Ellyson, S.L., & Dovidio, J.F. (1985). Power, dominance, and nonverbal behavior: Basic concepts and issues. In S.L. Ellyson & J.F. Dovidio (Eds.), *Power, dominance, and nonverbal behavior* (pp. 1-28). New York: Springer-Verlag.

Engeland, W.C., & Arnold, M.M. (2005). Neural circuitry in the regulation of adrenal corticosterone rhythmicity. *Endocrine*, *28*, 325-331.

Festinger, L. (1954). A theory of social comparison processes. *Human Relations*, *7*, 117-140.

Flinn, M.V., Geary, D.C., & Ward, C.V. (2005). Ecological dominance, social competition, and coalitionary arms races: Why humans evolved extraordinary intelligence. *Evolution and Human Behavior*, *26*, 10-46.

Frye, C. A., Rhodes, M. E., Rosellini, R., & Svare, B. (2002). The nucleus accumbens as a site of action for rewarding properties of testosterone and its 5α-reduced metabolites. *Pharmacology Biochemistry and Behavior*, *74*, 119-127.

Garcia, S. M., Tor, A., & Schiff, T. M. (2013). The psychology of competition a social comparison perspective. *Perspectives on Psychological Science*, *8*, 634-650.

Geniole, S.N., Bird, B.M., Ruddick, E.L., & Carré, J.M. (2017) Effects of competition outcome on testosterone concentrations in humans: An updated meta-analysis. *Hormones and Behavior*, *92*, 37-50.

Geniole, S.N., Busseri, M.A., & McCormick, C.M. (2013). Testosterone dynamics and psychopathic personality traits independently predict antagonistic behavior towards the perceived loser of a competitive interaction. *Hormones and Behavior*, *64*, 790-798.

Gladue, B. A., Boechler, M., & McCaul, K. D. (1989). Hormonal response to competition in human males. *Aggressive Behavior*, *15*, 409-422.

Gleason, E.D., Fuxjager, M.J., Oyegbile, T.O., & Marler, C.A. (2009). Testosterone release and social context: When it occurs and why. *Frontiers in Neuroendocrinology*, *30*, 460-469.

Gledhill, J., Bender, B., Larsen, M.T. (1988). *State and society: The emergence and development of social hierarchy and political centralization*. Boston: Unwin Hyman.

Gonzalez-Bono, E., Salvador, A., Serrano, M. A., & Ricarte, J. (1999). Testosterone, cortisol, and mood in a sports team competition. *Hormones and Behavior*, *35*, 55-62.

Goymann, W., & Wingfield, J.C. (2004). Allostatic load, social status and stress hormones: The cost of social status matter. *Animal Behaviour*, *67*, 591-602.

Granger, D. A., Kivlighan, K. T., Fortunato, C., Harmon, A. G., Hibel, L. C., Schwartz, E. B., & Whembolua, G. L. (2007). Integration of salivary biomarkers into developmental and behaviorally-oriented research: problems and solutions for collecting specimens. *Physiology & Behavior*, *92*, 583-590.

Granger, D. A., Shirtcliff, E. A., Booth, A., Kivlighan, K. T., & Schwartz, E. B. (2004). The “trouble” with salivary testosterone. *Psychoneuroendocrinology*, *29*, 1229-1240.

Grant, V., & France, J.T. (2001). Dominance and testosterone in women. *Biological Psychology*, *58*, 41-47.

Gruenewald, T.L., Kemeny, M.E., & Aziz, N. (2006). Subjective social status moderates cortisol responses to social threat. *Brain, Behavior, and Immunity*, *20*, 410-419.

Guezennec, C.Y., Lafarge, J.P., Bricout, V.A., Merino, D., & Serrurier, B. (1995). Effect of competition stress on tests used to assess testosterone administration in athletes. *International Journal of Sports Medicine*, *16*, 368-372.

Hamilton, L.D., Carré, J.M., Mehta, P.H., Olmstead, N., & Whitaker, J.D. (2015). Social neuroendocrinology of status: A review and future directions. *Adaptive Human Behavior and Physiology*, *1*, 202-230.

Hellhammer, D.H., Buchtal, J., Gutberlet, I., & Kirschbaum, C. (1997). Social hierarchy and andrenocortical stress reactivity in men. *Psychoneuroendocrinology*, *22*, 643-650.

Henry, A., Sattizahn, J.R., Norman, G. J., Beilock, S.L., & Maestripieri, D. (2017). Performance during competition and competition outcome in relation to testosterone and cortisol among women. *Hormones and Behavior*, *92*, 82-92.

Hermans, E. J., Bos, P. A., Ossewaarde, L., Ramsey, N. F., Fernández, G., & van Honk, J. (2010). Effects of exogenous testosterone on the ventral striatal BOLD response during reward anticipation in healthy women. *Neuroimage*, *52*, 277-283.

Hermans, E. J., Putman, P., Baas, J. M., Koppeschaar, H. P., & van Honk, J. (2006). A single administration of testosterone reduces fear-potentiated startle in humans. *Biological Psychiatry*, *59*, 872-874.

Hermans, E. J., Ramsey, N. F., & van Honk, J. (2008). Exogenous testosterone enhances responsiveness to social threat in the neural circuitry of social aggression in humans. *Biological Psychiatry*, *63*, 263-270.

Jiménez, M., Aguilar, R., & Alvero-Cruz, J.R. (2012). Effects of victory and defeat on testosterone and cortisol response to competition: Evidence for same response patterns in men and women. *Psychoneuroendocrinology*, *37*, 1577-1581.

Johnson, E.O., Kamilaris, T.C., Chrousos, G.P., & Gold, P.W. (1992). Mechanisms of stress: A dynamic overview of hormonal and behavioral homeostasis. *Neuroscience and Biobehavioral Reviews*, *16*, 115–130.

Josephs, R. A., Newman, M. L., Brown, R. P., & Beer, J. M. (2003). Status, testosterone, and human intellectual performance: Stereotype threat as status concern. *Psychological Science*, *14*, 158-163.

Josephs, R.A., Sellers, J.G., Newman, M.L., & Mehta, P.H. (2006). The mismatch effect: When testosterone and status are at odds. *Journal of Personality and Social Psychology*, *90*, 999-1013.

Kemper, T.D. (1990). *Social Structure and Testosterone: Explorations of the Socio-Bio-Social Chain*. New Jersey: Rutgers University Press.

Knight, E. L., & Mehta, P. H. (2014). Hormones and Hierarchies. In Cheng, Tracy, & Anderson (Eds.), *The psychology of social status* (269-302). New York: Springer.

Knight, E.L., & Mehta, P.H. (2017). Hierarchy stability moderates the effect of status on stress and performance in humans. *Proceedings of the National Academy of Sciences*, *114*, 78-83.

Kornienko, O., Clemans, K.H., Out, D., & Granger, D.A. (2014). Hormones, behavior, and social network analysis: Exploring associations between cortisol, testosterone, and network structure. *Hormones and Behavior*, 66, 534-544.

Kornienko, O., Schaefer, D.R., Weren, S., Hill, G.W., & Granger, D.A. (2016). Cortisol and testosterone associations with social network dynamics. *Hormones and Behavior*, *80,* 92-102.

Kudielka, B.M., Hellhammer, D.H., & Wüst, S. (2009). Why do we respond so differently? Reviewing determinants of human salivary cortisol responses to challenge. *Psychoneuroendocrinology*, *34*, 2-18.

Magee, J. C., & Galinsky, A. D. (2008). Social hierarchy: The self- reinforcing nature of power and status. *Academy of Management Annals*, *2,* 351–398.

Maner, J. K., Miller, S. L., Schmidt, N. B., & Eckel, L. A. (2008). Submitting to defeat: Social anxiety, dominance threat, and decrements in testosterone. *Psychological Science*, *19*, 764-768.

Mazur, A. (1985). A biosocial model of status in face-to-face primate groups. *Social Forces*, *64,* 377-402.

Mazur, A. (2017). Testosterone in biosociology: A memoir. *Hormones and Behavior*, *92*, 3-8.

Mazur, A., & Booth, A. (1998). Testosterone and dominance in men. *Behavioral and Brain Sciences*, *21*, 353-397.

Mazur, A. & Booth, A. (2014). Testosterone is related to deviance in male army veterans, but relationships are not moderated by cortisol. *Biological Psychology*, *96*, 72-76.

Mazur, A., & Lamb, T. A. (1980). Testosterone, status, and mood in human males. *Hormones and Behavior*, *14*, 236-246.

Mazur, A., Susman, E. J., & Edelbrock, S. (1997). Sex difference in testosterone response to a video game contest. *Evolution and Human Behavior*, *18*, 317-326.

Mazur, A., Welker, K.M., & Peng, B. (2015). Does the Biosocial Model explain the emergence of status differences in conversations among unacquainted men? *PLoS One*, *10*, e0142941.

McCaul, K. D., Gladue, B. A., & Joppa, M. (1992). Winning, losing, mood, and testosterone. *Hormones and Behavior*, *26*, 486-504.

McEwen, B. (1998). Stress, adaptation, and disease: Allostasis and allostatic load. *Annals of the New York Academy of Sciences*, *840,* 33-44.

McEwen, B. (2000). Allostasis and allostatic load: Implications for Neuropsychopharmacology. *Neuropsychopharmacology*, *22*, 108-124.

McEwen, B. (2004). Protection and damage from acute and chronic stress: Allostasis and allostatic overload and relevance to the pathophysiology of psychiatric disorders. *Annals of the New York Academy of Sciences*, *1032*, 1-7.

Mehta, P.H., DesJardins, N.M.L., van Vugt, M., & Josephs, R.A. (2017). Hormonal underpinnings of status conflict: Testosterone and cortisol are related to decisions and satisfaction in the hawk-dove game. *Hormones and Behavior,* 92, 141-154.

Mehta, P.H., Jones, A.C., & Josephs, R.A. (2008). The social endocrinology of dominance: Basal testosterone predicts cortisol changes and behavior following victory and defeat. *Journal of Personality and Social Psychology, 94*, 1078-1093.

Mehta, P.H. & Josephs, R.A. (2006). Testosterone change after losing predicts the decision to compete again. *Hormones and Behavior, 50*, 684-692.

Mehta, P.H., & Josephs, R.A. (2010). Testosterone and cortisol jointly regulate dominance: Evidence for a dual-hormone hypothesis. *Hormones and Behavior, 58*, 898–906.

Mehta, P.H., Mor, S., Yap, A.J., & Prasad, S. (2015c). Dual-hormone changes are related to bargaining performance. *Psychological Science, 26*, 866-876.

Mehta, P.H. & Prasad, S. (2015). The dual-hormone hypothesis: A brief review and future research agenda. *Current Opinions in Behavioral Science, 3*, 163-168.

Mehta, P.H., Snyder, N.A., Knight, E.L., & Lasseter, B. (2015b). Close versus decisive victory moderates the effect of testosterone change on competitive decisions and task enjoyment. *Adaptive Human Behavior and Physiology, 1*, 291-311.

Mehta, P.H, van Son, V., Welker, K.M., Prasad, S., Sanfey, A.G., Smidts, A., Roelofs, K. (2015a). Exogenous testosterone in women enhances and inhibits competitive decision-making depending on victory-defeat experience and trait dominance. *Psychoneuroendocrinology, 60*, 224-236.

Mehta, P.H., Wuehrmann, E.V., & Josephs, R.A. (2009). When are low testosterone levels advantageous? The moderating role of individual versus intergroup competition. *Hormones and Behavior, 56*, 158-162.

Montgomery, M.A., & Elimelech, M. (2007). Water and sanitation in developing countries: Including health in the equation. *Environmental Science & Technology, 41*, 17-24.

Montoya, E. R., Bos, P. A., Terburg, D., Rosenberger, L. A., & van Honk, J. (2014). Cortisol administration induces global down-regulation of the brain's reward circuitry. *Psychoneuroendocrinology*, *47*, 31-42.

Nave, G., Nadler, A., Zava, D., & Camerer, C. (2017). Single dose testosterone administration impairs cognitive reflection in men. *Psychological Science*, in press.

Neave, N., Laing, S., Fink, B., & Manning, J.T. (2003). Second to fourth digit ratio, testosterone and perceived male dominance. *Proceedings of the Royal Society B, 270*, 2167-2172.

Neave, N., & Wolfson, S. (2003). Testosterone, territoriality, and the ‘home advantage’. *Physiology & Behavior*, *78*, 269-275.

Newman, M. L., & Josephs, R. A. (2009). Testosterone as a personality variable. *Journal of Research in Personality*, *43*, 258-259.

Newman, M. L., Sellers, J. G., & Josephs, R. A. (2005). Testosterone, cognition, and social status. *Hormones and Behavior*, *47,* 205-211.

Norman, R. E., Moreau, B. J., Welker, K. M., & Carré, J. M. (2015). Trait anxiety moderates the relationship between testosterone responses to competition and aggressive behavior. *Adaptive Human Behavior and Physiology*, *1*, 312-324.

O'Cass, A., & McEwen, H. (2004). Exploring consumer status and conspicuous consumption. *Journal of Consumer Behaviour*, *4*, 25-39.

Oliveira, T., Gouveia, M. J., & Oliveira, R. F. (2009). Testosterone responsiveness to winning and losing experiences in female soccer players. *Psychoneuroendocrinology, 34*, 1056-1064.

Oliveira, G. A., Uceda, S., Oliveira, T. F., Fernandes, A. C., Garcia-Marques, T., & Oliveira, R. F. (2014). Testosterone response to competition in males is unrelated to opponent familiarity or threat appraisal. *Frontiers in Psychology*, *5*, 1240.

Oliveira, G.A., & Oliveira, R.F. (2014). Androgen responsiveness to competition in humans: The role of cognitive variables. *Neuroscience and Neuroeconomics*, *3*, 19-32.

Oxford, J., Ponzi, D., & Geary, D. C. (2010). Hormonal responses differ when playing violent video games against an ingroup and outgroup. *Evolution and Human Behavior*, *31*, 201-209.

Packard, M.G., Cornell, A.H., & Alexander, G.M. (1997). Rewarding affective properties on intra-nucleus accumbens injections of testosterone. *Behavioral Neuroscience*, *111*, 219-224.

Peters, B.J., Hammond, M.D., Reis, H.T., & Jamieson, J.P. (2016). The consequences of having a dominant romantic partner on testosterone responses during a social interaction. *Psychoneuroendocrinology*, *74*, 308-315.

Pew Research Center (2017, January 12). Social Media Fact Sheet. Retrieved from http://www.pewinternet.org/fact-sheet/social-media/

Phoenix, C.H., Goy, R.W., Gerall, A.A., & Young, W.C. (1959). Organizing action of prenatally administered testosterone propionate on the tissues mediating mating behavior in the female guinea pig. *Endocrinology*, *65*, 369-382.

Phoenix, C.H., Slob, A.K., & Goy, R.W. (1973). Effects of castration and replacement therapy on sexual behavior of adult male rhesuses. *Journal of Comparative and Physiological Psychology*, *84*, 472-481.

Ponzi, D., Zilioli, S., Mehta, P.H., Maslov, A., & Watson, N.V. (2016). Social network centrality and hormones: The interaction of testosterone and cortisol. *Psychoneuroendocrinology*, *68*, 6-13.

Popma, A., Vermeiren, R., Geluk, C.A., Rinne, T., van den Brink, W., Knol, D.L., Jansen, L.M.C., van Engeland, H., & Doreleijers, T. A. (2007). Cortisol moderates the relationship between testosterone and aggression in delinquent male adolescents. *Biological Psychiatry*, *61*, 405-411.

Pratto, F., Sidanius, J., Stallworth, L. M., & Malle, B. F. (1994). Social dominance orientation: A personality variable predicting social and political attitudes. *Journal of Personality and Social Psychology*, *67*, 741-763.

Purifoy, F.E., & Koopmans, L.H. (1979). Androstenedione, testosterone, and free testosterone concentration in women of various occupations. *Social Biology*, *26*, 179-188.

Radke, S., Volman, I., Mehta, P., van Son, V., Enter, D., Sanfey, A., Toni, I., de Bruijn, E.R.A., & Roelofs, K. (2015). Testosterone biases the amygdala toward social threat approach. *Science Advances*, *1*, e1400074.

Romano, J.F. (1990). *Death, burial, and afterlife in ancient Egypt*. Pittsburgh, PA: Carnegie Museum of Natural History.

Ronay, R., & Carney, D.R. (2013). Testosterone's negative relationship with empathic accuracy and perceived leadership ability. *Social Psychological and Personality Science*, *4*, 92-99.

Ronay, R., Greenaway, K., Anicich, E. M., & Galinsky, A. D. (2012). The path to glory is paved with hierarchy: When hierarchical differentiation increases group effectiveness. *Psychological Science*, *23*, 669-677.

Rose, R.M., Bernstein, I.S., & Gordon, T.P. (1975). Consequences of social conflict on plasma testosterone levels in rhesus monkeys. *Psychosomatic Medicine*, *37*, 50-61.

Salvador, A., & Costa, R. (2009). Coping with competition: neuroendocrine responses and cognitive variables. *Neuroscience & Biobehavioral Reviews*, *33*, 160-170.

Sapolsky, R.M. (1982). The endocrine stress-response and social status in the wild baboon. *Hormones and Behavior*, *16*, 279-292.

Sapolsky, R.M. (2004). Social status and health in humans and others animals. *Annual Review of Anthropology*, *33*, 393-418.

Sapolsky, R.M. (2005). The influence of social hierarchy on primate health. *Science*, *308*, 648-552.

Schultheiss, O.C. (2007). A biobehavioral model of implicit power motivation: arousal, reward, and frustration. In: Harmon-Jones, E., Winkielman, P. (Eds.), *Social Neuroscience: Integrating Biological and Psychological Explanations of Social Behavior*. Guilford Press, New York, pp. 176-196.

Schultheiss, O.C., Campbell, K.L., & McClelland, D.C. (1999). Implicit power motivation moderates men's testosterone responses to imagined and real dominance success. *Hormones and Behavior*, *36*, 234-241.

Schultheiss, O.C., & Rohde, W. (2002). Implicit power motivation predicts men's testosterone changes in implicit learning in a contest situation. *Hormones and Behavior*, *41*, 195-202.

Schultheiss, O.C. Wirth, M.M., Torges, C.M., Pang, J.S., Villacorta, M.A., & Welsh, K.M. (2005). Effects of implicit power motivation on men's and women's implicit learning and testosterone changes after social victory or defeat. *Journal of Personality and Social Psychology*, *88*, 174-188.

Sellers, J.G., Mehl, M.R., & Josephs, R.A. (2007). Hormones and personality: Testosterone as a marker of individual differences. *Journal of Research in Personality*, *41*, 126-138.

Sherman, G.D., Jooa, J.L., Cuddy, A.J.C., Renshon, J., Oveis, C., Gross, J.J., Lerner, J.S. (2012). Leadership is associated with lower levels of stress. *PNAS*, *109*, 17903-17907.

Sherman, G.D., Lerner, J.S., Josephs, R.A., Renshon, J., & Gross, J.J. (2016). The interaction of testosterone and cortisol is associated with attained status in male executives. *Journal of Personality and Social Psychology*, *110*, 921-929.

Sherman, G.D., Rice, L. K., Jin, E.S., Jones, A.S., & Josephs, R.A. (2017). Sex Differences in Cortisol's Regulation of Affiliative Behavior. *Hormones and Behavior*, *92*, 20-28.

Shirtcliff, E. A., Peres, J. C., Dismukes, A. R., Lee, Y., & Phan, J. M. (2014). Riding the physiological roller coaster: Adaptive significance of cortisol stress reactivity to social contexts. *Journal of Personality Disorders*, *28*, 40-51.

Sidanius, J., Pratto, F., Van Laar, C., & Levin, S. (2004). Social dominance theory: Its agenda and method. *Political Psychology*, *25*, 845-880.

Sidanius, J. & Pratto, F. (1999). *Social dominance: An intergroup theory of social hierarchy and oppression*. New York: Cambridge University Press.

Slatcher, R.B., Mehta, P.H., & Josephs, R. A. (2011). Testosterone and self-reported dominance interact to influence human mating behavior. *Social Psychological and Personality Science*, *2*, 531-539.

Smither, R. D., & Houston, J. M. (1992). The nature of competitiveness: The development and validation of the competitiveness index. *Educational and Psychological Measurement*, *52*, 407-418.

Sollberger, S., Bernauer, T., & Ehlert, U. (2016). Salivary testosterone and cortisol are jointly related to pro-environmental behavior in men. *Social Neuroscience*, *11*, 553-566.

Stanton, S. J., & Schultheiss, O. C. (2007). Basal and dynamic relationships between implicit power motivation and estradiol in women. *Hormones and Behavior*, *52*, 571-580.

Stanton, S. J., & Schultheiss, O. C. (2009). The hormonal correlates of implicit power motivation. *Journal of Research in Personality*, *43*, 942-949.

Starcke, K. & Brand, M. (2012). Decision making under stress: A selective review. *Neuroscience & Biobehavioral Reviews*, *36*, 1228-1248.

Steiner, E.T., Barchard, K.A., Meana, M., Hadi, F., & Gray, P.B. (2010). The deal on testosterone responses to poker competition. *Current Psychology*, *29*, 45-51.

Suay, F., Salvador, A., González-Bono, E., Sanchıs, C., Martınez, M., Martınez-Sanchis, S., Simón, V.M., & Montoro, J.B. (1999). Effects of competition and its outcome on serum testosterone, cortisol and prolactin. *Psychoneuroendocrinology*, *24*, 551-566.

Tackett, J.L., Herzhoff, K., Harden, K.P., Page-Gould, E., & Josephs, R.A. (2014). Personality × hormone interactions in adolescent externalizing psychopathology. *Personality Disorders: Theory, Research, and Treatment*, *5*, 235.

Taylor, J.H. (2001). *Death and the afterlife in ancient Egypt*. Chicago: University of Chicago Press.

Tiedens, L. Z., & Fragale, A. R. (2003). Power moves: Complementarity in dominant and submissive nonverbal behavior. *Journal of Personality and Social Psychology*, *84*, 558.

Tremblay, M.S., Copeland, J.L., & van Helder, W. (2005). Influence of exercise duration on post-exercise steroid responses in trained males. *European Journal of Applied Physiology*, *94*, 505-513.

Tremblay, R.E., Schaal, B., Boulerice, B., Arseneault, L., Soussignan, R.G., Paquette, D., & Laurent, D. (1998). Testosterone, physical aggression, dominance, and physical development in early adolescence. *International Journal of Behavioral Development, 22*, 753-777.

Tsigos, C., & Chrousos, G.P. (2002). Hypothalamic-pituitary-adrenal axis, neuroendocrine factors and stress. *Journal of Psychosomatic Research*, *53*, 865-871.

van Anders, S. M., & Watson, N. V. (2007). Effects of ability-and chance-determined competition outcome on testosterone. *Physiology & Behavior*, *90*, 634-642.

van Bokhoven, I., van Goozen, S. H., van Engeland, H., Schaal, B., Arseneault, L., Séguin, J. R., Assaad, J., Nagin, D.S., Vitaro, F., & Tremblay, R. E. (2006). Salivary testosterone and aggression, delinquency, and social dominance in a population-based longitudinal study of adolescent males. *Hormones and Behavior*, *50*, 118-125.

van den Bos, R., Harteveld, M., & Stoop, H. (2009). Stress and decision-making in humans: Performance is related to cortisol reactivity, albeit differently in men and women. *Psychoneuroendocrinology*, *34*, 1449-1458.

van der Meij, L., Buunk, A.P., Almela, M., & Salvador, A. (2010). Testosterone responses to competition: The opponent's psychological state makes it challenging. *Biological Psychology*, *84*, 330-335.

van der Meij, L., Schaveling, J., & van Vugt, M. (2016). Basal testosterone, leadership and dominance: A field study and meta-analysis. *Psychoneuroendocrinology*, *72*, 72-79.

van Honk, J., Montoya, E. R., Bos, P. A., Van Vugt, M., & Terburg, D. (2012). New evidence on testosterone and cooperation. *Nature*, *485*, E4-E5.

van Honk, J., & Schutter, D.J.L.G. (2007). Testosterone reduces conscious detection of signals serving social correction: Implications for antisocial behavior. *Psychological Science*, *18*, 663-667.

van Honk, J., Schutter, D.J., Bos, P.A., Kruijt, A.W., Lentjes, E.G., & Baron-Cohen, S. (2011). Testosterone administration impairs cognitive empathy in women depending on second-to-fourth digit ratio. *Proceedings of the National Academy of Sciences*, *108*, 3448-3452.

Viru, M., Hackney, A.C., Karelson, K., Janson, T., Kuus, M., & Viru, A. (2010). Competition effects on physiological responses to exercise: Performance, cardiorespiratory and hormonal factors. *Acta Physiologica Hungarica*, *97*, 22-30.

Wagner, J. D., Flinn, M. V., & England, B. G. (2002). Hormonal response to competition among male coalitions. *Evolution and Human Behavior*, *23*, 437-442.

Walker, R.E., Keane, C.R., & Burke, J.G. (2010). Disparities and access to healthy food in the United States: A review of food deserts literature. *Health & Place*, *16*, 876-884.

Welker, K.M., & Carré, J.M. (2015). Individual differences in testosterone predict persistence in men. *European Journal of Personality*, *29*, 83-89.

Welker, K. M., Lassetter, B., Brandes, C. M., Prasad, S., Koop, D. R., & Mehta, P. H. (2016). A comparison of salivary testosterone measurement using immunoassays and tandem mass spectrometry. *Psychoneuroendocrinology*, *71*, 180-188.

Welker, K.M., Lozoya, E., Campbell, J.A., Neumann, C.S., & Carré, J.M. (2014). Testosterone, cortisol, and psychopathic traits in men and women. *Physiology & Behavior*, *129*, 230-236.

Welker, K.M., Norman, R.E., Goetz, S., Moreau, B.J.P., Kitayama, S., & Carré, J.M. (2017). Preliminary evidence that testosterone's association with aggression depends on self-construal. *Hormones and Behavior*, *92*, 117-127.

Welling, L.L.M., Moreau, B.J.P., Bird, B.M., Hansen, S., & Carré, J.M. (2016). Exogenous testosterone increases men's perceptions of their own dominance. *Psychoneuroendocrinology*, *64*, 136-142.

Whitworth, J.A., Williamson, P.M., Mangos, G., & Kelly, J.J. (2005). Cardiovascular consequences of cortisol excess. *Vascular Health and Risk Management*, *1*, 291-299.

Wirth, M. M., & Schultheiss, O. C. (2007). Basal testosterone moderates responses to anger faces in humans. *Physiology & Behavior*, *90*, 496-505.

Wirth, M.M., Welsh, K.M., & Schultheiss, O.C. (2006). Salivary cortisol changes in humans after winning or losing a dominance contest depend on implicit power motivation. *Hormones and Behavior*, *49*, 346-352.

Wingfield, J.C. (2017). "The challenge hypothesis: Where it began and relevance to humans." *Hormones and Behavior*, *92*, 9-12.

Wingfield, J.C., Hegner, R.E., Dufty, A.M., Jr., & Ball, G.F. (1990). The "challenge hypothesis": Theoretical implications for testosterone secretion, mating systems, and breeding strategies. *The American Naturalist*, *136*, 829-846.

Wright, N.D., Bahrami, B., Johnson, E., Di Malta, G., Rees, G., Frith, C. D., & Dolan, R.J. (2012). Testosterone disrupts human collaboration by increasing egocentric choices. *Proceedings of the Royal Society B*, *279*, 2275-2280.

Wu, Y., Eisenegger, C., Zilioli, S., Watson, N.V., & Clark, L. (2017). Comparison of clear and narrow outcomes on testosterone levels in social competition. *Hormones and Behavior*, *92*, 51-56.

Zilioli, S., Mehta, P. H., & Watson, N. V. (2014). Losing the battle but winning the war: Uncertain outcomes reverse the usual effect of winning on testosterone. *Biological Psychology*, *103*, 54-62.

Zilioli, S., & Watson, N. V. (2013). Winning isn't everything: Mood and testosterone regulate the cortisol response in competition. *PLoS One*, *8*, e52582.

Zilioli, S., & Watson, N. V. (2014). Testosterone across successive competitions: Evidence for a 'winner effect' in humans? *Psychoneuroendocrinology*, *47*, 1-9.

Zyphur, M.J., Narayanan, J., Koh, G., & Koh, D. (2009). Testosterone-status mismatch lowers collective efficacy in groups: Evidence from a slope-as-predictor multilevel structural equation model. *Organizational Behavior and Human Decision Processes*, *110*, 70-79.