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# Intercollegiate cross-country competition: Racing is associated with a substantial increase in salivary levels of cortisol and testosterone in men and women

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Intercollegiate Cross-Country Competition: Racing is Associated with a Substantial  
Increase in Salivary Levels of Cortisol and Testosterone in Men and Women

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## Abstract

Athletic competition, containing both psychological and physical components, has been shown to be associated with levels of testosterone (T) and cortisol (C) in anticipation of, and during, competition. In the current research, 16 male and 22 female members of a collegiate cross country team gave saliva samples before warm-up, after warm-up, and immediately after the finish of an intercollegiate cross-country meet. Finish times were recorded as a measure of performance outcome. Participants also completed the Mental Toughness in Sport Questionnaire (MTSQ). For both men and women, after-race levels of salivary C and T were substantially elevated relative to before and after warm-up levels. Among women, there was a significant interaction between before warm-up C and T in predicting finish time, such that low C predicted slower finish times only at lower levels of T. For males and females, the interaction of mental toughness beliefs and gender was revealed as a potentially important variable in explaining competition elevations of T and C. Increased hormone levels may result from physical exertion, the psychological effects of competition, or some combination of the two. Competition-related increases in C and T presumably benefit performance in cross country racing and other sports, but the exact character of these benefits remains to be determined.



## CHAPTER 1: Introduction

There are many factors both within and outside of the athlete's control that influence sport performance. Traditionally, most athletes and coaches focus the training regime on honing the physiological state of the body. However, with the rise of sport psychology (e.g., Williams, 2010) and concurrent rise in positive psychology (Seligman & Csikszentmihalyi, 2000), athlete training has expanded to include mental preparation through psychological intervention. Despite the abundant research elucidating the mind-body effects in sport performance and competition, much remains unknown regarding the process of *how* psychological processes influence and impact the physiology of the body in a sport setting. Thus, the purpose of the present study is to address this inquiry by exploring how the experience of sport competition, containing both physiological (e.g., exercise) and psychological (e.g., stress or status threat) components, impacts endocrine levels (T and C, specifically) of athletes competing in a cross-country race.

The initiation and maintenance of physical activity involves the activation of many areas of the central (CNS) and peripheral nervous systems (PNS). The sympathetic division of the autonomic branch of the PNS is one particularly important area as it is responsible for carrying out the oxygen and energy needs of the skeletal muscles as well as for regulation of the internal systems (i.e., heart functioning, circulation, and metabolism) (Borer, 2003). These actions are carried out, in part, by the release of hormones into the blood stream from the hypothalamic-pituitary-adrenal axis (HPA) and the hypothalamic-pituitary-gonadal axis (HPG) (Salvador, 2012). Engaged during exercise as well as psychological stress, activation of the HPA culminates in the release of cortisol (C) from the adrenal cortex and responds linearly to the intensity and

magnitude of the exercise or psychological stress (Borer, 2003). As a glucocorticoid, C is vital in the breakdown of muscle protein as well as the subsequent conversion of free amino acids into energy and the initiation of fat metabolism (Carlson, 2011). During the onset of environmental stressors, C regulates blood glucose supplying energy to muscles and the brain, thereby allowing the individual to adapt to increasing demands (Coelho, Keller, & Da Silva, 2010). Physical and social stress may also result in increased circulating testosterone (T). Although T is thought to primarily originate from the HPG, some evidence suggests it may not have a gonadal origin during exercise (Cumming, Brunsting, Strich, Ries, & Rebar, 1986). Testosterone, found in higher levels in men, has demonstrated advantageous effects on muscle mass, strength, and power, body fat composition, aerobic capacity, thermoregulation, and metabolism during exercise (Gatti & Palo, 2011). T has also been linked with several cognitive benefits including faster reaction time (Müller, 1994), better spatial perception and three-dimensional mental rotation abilities (Hooven, Chabris, Ellison, & Kosslyn, 2004), and increased spatial memory (Postma et al., 2000). The demonstrated connection between T and aggressive or dominant behavior, particularly in a setting where social status is relevant, has made T a variable of interest in athletic competition above and beyond its physiological benefits (Carré, McCormick, & Hariri, 2011). Studied together, T and C are both linked with improved neuromuscular adaptation from resistance training, endurance training, and a combination of both (e.g., Crewther, Cook, Cardinale, Weatherby, & Lowe, 2011; Kraemer & Spiering, 2006). In addition to the sustained benefits as a result of training, these hormones are implicated in preventing overreaction of the immune system as well

as enacting tissue rejuvenation necessary for repairing exercise induced muscle damage (Duclos, Guinot, & Le Bouc, 2007).

As such, changes in T and C in anticipation of and during athletic competition are of particular interest in understanding the dynamic role of these compounds in influencing behaviors, including performance. This is due to the prevalent psychological and physiological demands of competition-in which T and C may offer adaptive benefit toward. Recent research has begun to uncover recognizable endocrine patterns in relation to competition. More specifically, actual competition in a team sport setting is related to a large increase in salivary T and C (Bateup, Booth, Shirtcliff, & Granger, 2002; Edwards & Kurlander, 2010). Several studies have also shown a rise in T in anticipation of competition (Booth, Shelly, Mazur, Tharp, & Kittok, 1989; Edwards & Kurlander, 2010; Oliveira, Gouveia, & Oliveira, 2009). Research demonstrating a rise in C in anticipation during competition and the performance benefit of such an effect are widely debated (Alix-Sy, Le Scanff, & Filaire, 2008; Kivlighan, Granger, & Booth, 2005; Salvador, Suay, González-Bono, & Serrano, 2003). Few of these studies have explored this competition effect across gender, among endurance athletes (who compete consistently from start to finish of a race), or longitudinally across different competitions for the same athletes. Furthermore, even fewer studies have looked at how T and C levels change from before to after warm-up and from after-warm-up to after competition to explore to unique effects of competition compared to exercise in preparation for competition.

Therefore, the specific main purpose of the present study was to observe patterns of T and C before warm-up, after warm-up, and after a cross-country competition across gender and time. Based on previous research with team sports such as soccer, volleyball,

and tennis (Edwards & Kurlander, 2010; Edwards et al., 2006) it was hypothesized that competition specifically would result in significantly elevated levels of both T and C. Further, this elevation would be substantially greater than hypothesized anticipatory increases in T and C leading up to competition. A secondary purpose was to explore the effect of T and C before and during competition as a possible predictor of performance. Additionally, mental toughness, a psychological construct, was explored as a possible variable in explaining predicted competition elevations in T and C.

## CHAPTER 2: Review of Literature

To gain a greater understanding of the empirical and theoretical background and basis for the present study, this chapter will review relevant literature. First, research pertaining to the demonstrated behavioral correlates of T and C will be discussed. This will lay the framework for the importance of both T and C as potential markers of a psychological experience in addition to the aforementioned physiological benefits. Narrowing this framework with regards to the present study, this discussion will be followed by a review of research that explores T and C levels prior to and during athletic competition. This will introduce the reader to prior research that the present study is specifically designed to build upon. Following this section, mental toughness, a previously unexamined psychological variable in relation to T and C, will be introduced. The inclusion of mental toughness and its presentation following the discussion of studies observing T and C in competition will signify one of several ways in which the present study will build upon previous research. Finally, this chapter will conclude with a summary of the purpose and specific hypotheses of the present study.

### *Behavioral Correlates of Cortisol*

Aside from its many important biological functions, C also has received attention for its predominant role in the physical as well as psychological response to stress. As previously mentioned, this hormone is released from the adrenal cortex when the HPA is activated by the autonomic nervous system. The HPA is rooted in the evolutionary development of the human brain as being responsible for initiating the “fight or flight” response to an environmental threat to well-being. Despite the seemingly simple initial purpose, this system of activation has been demonstrated to have many complex

relationships with a variety of psychosocial and physiological factors. More specifically, higher levels of C have been related to negative affect (Erickson, Drevets, & Schulkin, 2003; Velders et al., 2011), aging (Strahler, Mueller, Rosenloecher, Kirschbaum, & Rohleder, 2010), reduced novelty seeking (Laudenslager, Jorgensen, Grzywa, & Fairbanks, 2011), performance anxiety (Filaire, Alix, Ferrand, & Verger, 2009), math anxiety and math performance (Pletzer, Wood, Moeller, Nuerk, & Kerschbaum, 2010), lack of resource control (Plusquellec et al, 2011), increased heart rate in response to psychological stress (Almela et al., 2011), and athletic competition (Edwards & Kurlander, 2010). Related to the purpose of the present research, the relationship between C and athletic competition will be explored in greater detail.

#### *Behavioral Correlates of Testosterone*

Although found in both men and women, T is expressed in greater concentrations in men and is responsible for many gender-related physical differences (e.g., muscle mass and body hair). In addition, as a sex hormone, it has demonstrated both theoretical and experimental relationships with various mate attraction behaviors in men. Furthermore, Renninger, Wade, and Grammer (2004) showed that males who successfully made contact in a courtship initiation engaged in pre-contact behaviors that indicate status, such as space-maximizing body movement, intra-sex touching (e.g., when one male places his hands or arms on another man's shoulders or back, interpreted as a show of dominance), and open-body gesturing. From an evolutionary perspective, these behaviors are intended to indirectly enhance the likelihood of reproduction by not only attracting the attention of women, but also signifying non-verbal cues of fitness and superior social status (Burgoon, 1991; Mehrabian, 1972).

As a result, T has adopted the somewhat secondary characteristic of indicating social status in relation to the expression of dominant behaviors (Archer, 2006; Newman, Sellers, & Jacob, 2005). In fact, dominance, operationally defined as “the motivation to achieve high social status by obtaining power, influence, or valued prerogatives over others” (Eisenegger, Haushofer, & Fehr, 2011, p.263), has been related to T levels in both men and women (Mazur & Booth, 1998). Mehta and Josephs (2010) additionally found that the relationship between T and dominance was dependent upon levels of C, and thus suggested a dual-hormone approach when investigating status seeking behaviors. Aggression, a more overt physically or verbally harmful dominance related behavior, has demonstrated mixed results with respect to T levels (Eisenegger et al., 2011). Despite conflicting evidence in the behavioral expression of aggression, recent research suggests that the emotional expression of anger does have a more clear relationship with T (Peterson & Harmon-Jones, 2011). Interestingly, although T may be involved in evoking anger, it also is correspondingly involved in reducing the ability to accurately infer emotion in others, thereby creating a complex, one-sided emotional response (Hermans, Putnam, & van Honk, 2006).

There also is a growing body of literature that has demonstrated a positive association between T and risk-taking in social (e.g., Middleman & DuRant, 1996) as well as economic domains (e.g., Apicella et al., 2008; Stanton, Lienen, Schultheiss, 2011). Similarly, studies have shown that T may increase willingness to engage in competition as well as rise in response to positive outcomes (Mehta & Josephs, 2006; Oliveira et al., 2009). These two behavioral correlates of T, risk-taking and willingness

to engage in competition, are of particular relevance for the present study, as they may have some impact on performance and endocrine profiles of athletes in competition.

### *Cortisol and Testosterone in Athletic Competition*

Understanding the pattern of these two hormones in athletic competition is of great interest due to their demonstrated relationship with physiological stress and arousal as well as psychological and behavioral characteristics that may impact performance (e.g., anxiety, confidence, risk-taking, and aggression). As such, researchers recently have begun to elucidate the endocrine profile of testosterone and C in competition settings.

*Anticipatory rise in cortisol and testosterone.* Although some researchers have shown a rise in C prior to competition, compared to rest days and time periods earlier in the day (Alix-Sy et al., 2008; Bateup et al., 2002; Booth et al., 1989; Salvador et al., 2003), Edwards and Kurlander (2010) show that, within an hour of competition, C does not significantly change. In observing male and female collegiate tennis players, Filaire et al. (2009) showed that C increased steadily from baseline levels throughout the day leading up to competition and peaked shortly after the competition was completed. Furthermore, C levels, as well as psychological indices of anxiety, were significantly higher in athletes that lost versus athletes that won their match. Implications from this study suggest that an anticipatory rise in C prior to competition, possibly due to a psychological stress response outside of physical exertion, may occur based on individual differences related to performance outcomes. This finding supported evidence from an earlier study conducted by Eubank, Collins, Lovell, Dorling, and Talbot (1997) that also showed an individual difference in the rise in C in preparation for competition.



Specifically, this study found that although C showed an increase leading up to competition for both groups, athletes who perceived their pre-competition anxiety as facilitative to performance showed consistently lower levels of C compared to athletes that perceived their anxiety as debilitating. Taken together, these studies suggest that individual differences in how people perceive competition in anticipation of an athletic competition, results in physiological changes in the body that impacts levels of C and may further impact performance.

A similar rise in testosterone in preparation for competition also has been demonstrated (Bateup et al., 2002; Booth et al., 1989; Edwards & Kurlander, 2010; Suay et al. 1999). Anticipatory rise in T is thought to result in several advantageous psychological preparatory mechanisms related to performance. These demonstrated advantages include an increase in competitiveness, risk-taking, and dominance (previously discussed), as well as an increase in psychomotor as well as cognitive functioning (Janowsky, 2006). As such, it has been theorized that an anticipatory rise in T would allow for better adjustment to the demanding competition environment (Salvador et al., 2003). However, studies have revealed mixed findings with regard to a rise in T prior to competition and the actual performance outcome (i.e., winning or losing). Although Salvador, et al. (2003) showed an anticipatory rise in T only among judo fighters that won the competition, Oliveira, et al. (2003) found an anticipatory rise in T only among players of a soccer team that lost the competition. In general, more research is necessary to understand anticipatory changes in T and C and how these changes related to performance outcomes.

*Endocrine patterns before, during, and after competition.* Although the anticipatory rise in both cortisol and testosterone offers particularly interesting implications with regard to the psychological preparatory mechanisms related to impending competition, the endocrine patterns directly associated with the actual event are perhaps of greater interest. This is due to the complex nature of competition in that it involves the psychological aspect in addition to physical exertion, both of which have independently demonstrated relationships with testosterone and cortisol. Possibly due to the innate complications involved with collecting physiological data during actual competition, very few studies have observed both testosterone and cortisol before, during, and after competition.

In capturing the interaction of physiological and psychological arousal associated with competition, Edwards and Kurlander (2010) measured the salivary levels of T and C in female collegiate volleyball and tennis players before warm-up, mid-warm-up, after warm-up, and after competition as well as before and after practice. Unlike earlier studies that showed an anticipatory rise in C, this study found that C remained stable from before warm-up to mid-warm-up. Similar to previous studies (e.g., Filaire et al., 2009), C was found to be highest when measured directly after competition. On the other hand, T did show an anticipatory response in addition to reaching the highest point in the sample collected directly after competition. Although less dramatic than competition increases for C, both T and C increased during practice as well. Indicating the importance of physical participation in the competition, as opposed to just being within the competition environment, this study showed that the rise in these hormones during competition was demonstrated only among athletes that played in the match. In fact, C

and T levels actually dropped for athletes that warmed-up, but did not play in the game or match (Edwards & Kurlander, 2010). Collectively, findings from this study suggest that a still undetermined element involving the psychological and physical aspects of sport results in a consistent elevation of T and C during competition.

Kivlighan et al. (2005) suggests that there are individual differences in T and C levels during competition for males and females by showing a competition related increase in T for men, but not women during a competitive rowing task. In addition to possible gender differences in endocrine patterns during competition, T and C levels may also be different for individuals with more positive outcomes. However, findings to support this notion are mixed. Although some research has shown that T, but not C levels after competition are higher among winners (Bateup et al., 1989; McCaul, Gladue, & Joppa, 1992), other research has shown no difference in T or C levels between winners and losers after competition (Gonzalez-Bono, Salvador, Serrano, & Ricarte, 1999). Furthermore, in addressing the possibility for differences based on outcome or gender, numerous studies have demonstrated the increasingly consistent finding that both C and T significantly increase as a result of athletic competition independent of performance outcome (i.e., win/loss) and among women (Bateup et al., 2002; Coelho et al., 2010; Edwards & Wetzel, & Wayner, 2006; & González-Bono et al., 1999). Taking a collective perspective on the aforementioned studies, there exists presently a great need for further research to both confirm these patterns exist ubiquitously across different competition settings and across gender as well as begin to explore in greater detail the co-occurrence of psychological factors in relation to physiological arousal and competition.

*Mental Toughness and the Endocrine Profile*

One such psychological factor that may contribute to the understanding of hormones in competition is the construct of *mental toughness*. The inclusion of this variable builds upon previous studies involving endocrine patterns in competition, as it may address unique contributions of psychological functioning in explaining fluctuations in T and C during competition. Early work with the idea of toughness in relation to sport performance laid the framework for current understandings of the term, mental toughness. Dienstbier (1989) provided a comprehensive review on stress, arousal, and associated physiological responses and discussed the phenomenon in which habitual exposure to a stressor may result in adaptive changes in the neuroendocrine system termed *physiological toughness*. Specifically, arousal associated with positive emotions tends to result in a cascade of effects, including the activation of the sympathetic-adrenal-medullary (SAM) pathway that results in the release of catecholamines and an increase in cardiac activity. This cardiac activity is coupled with a widening of the blood vessels (a decrease in vascular resistance) caused by the presence of the catecholamine, epinephrine. These changes result in a physiological state that is more adaptive for functioning as the increase of blood flow to the brain and muscles provides greater access to resources (Jones, Meijen, McCarthy, & Sheffield, 2009). Dienstbier (1989) further proposed that both passive and active (i.e., regular exercise) toughening could occur with long-term exposure to a stressor, thus the aforementioned term physiological toughness. This physiological toughening resulting from a positive view of physical and psychological arousal has been shown to correlate with an increase in catecholamine availability and responsiveness. Further, this adaptation seems to vary among individuals,

but overall has been shown to result in improved performance, increased tolerance to stress, greater emotional stability, an immune system enhancement (Dienstbier, 1991).

Branching from the physiological toughening model, mental toughness has been developed to describe the psychological aspect of toughening (the development of superior psychological responding) in response to competition challenges. This construct is both derived to be specific to a sport/competition setting and largely based in psychological theory, rather than physiology. Although many athletes and coaches can subjectively describe the concept of mental toughness in sport, these personal definitions often lack operational conformity. In describing the complex, multidimensional aspect of mental toughness, Harmison (2011) defined seven mental toughness attributes: being confident, summoning motivation and desire, effectively dealing with adversity and failure, overcoming physical and/or emotional pain and hardship, successfully managing anxiety, pressure, and other emotions, staying focused, and finding balance and keeping perspective. Further, Jones, Hanton, and Connaughton (2002) refer to mental toughness as a construct that can be learned and represents a general ability to cope with the demands of competition in addition to remaining consistently determined, focused, confident, and in control relative to an opponent. Crust (2007) reviewed several studies that demonstrate a relationship between mental toughness and actual performance on a cognitive task (Clough, Earle, & Sewell, 2002), athletic skill (Thomas, Schlinker, & Over, 1996), and perceived exertion (Clough & Earle, 2002). Furthermore, Harmison (2011) described mental toughness as a social-cognitive personality construct that may be modified over time if “new learning, development, or biochemical changes take place within the athlete” (p. 48). This suggests that perhaps aspects of mental toughness may

be influenced by the long-term changes in physiology that matriculate from Dienstbier's model for physiological toughness. In addition to following or changing as a result of biological toughening, mental toughness may precede physiological changes by encouraging the challenge (as opposed to threat) perception in relation to an impending competition. Thus, in addition to connections with physiological toughening and traditional performance outcomes in competition, mental toughness also may be related to physiological functioning (i.e., the neuroendocrine system). As such, mental toughness may play some role in explaining psychologically elicited changes in T and or C during competition and will therefore, be explored in the present study as a potential predictor of T and C levels.

#### *Purpose of the Present Study*

The primary purpose of the present study is to extend previous research that has measured T and C during team competition by measuring salivary T and C before warm-up, after warm-up, and after competition for both male and female endurance athletes. Specifically, samples will be collected from a varsity men's and women's collegiate cross-country team during an intercollegiate cross-country race. It is hypothesized that T, but not C will increase in anticipation of competition. Furthermore, it is hypothesized that T and C will both significantly increase during competition, above and beyond changes seen prior to competition. Due to the fact that few, if any studies have looked at endocrine patterns longitudinally, the present study will examine the consistency of the endocrine patterns of competitive athletes over time. This will be done by comparing samples collected in the present study with T and C samples collected at the same event one year prior, under similar conditions, for athletes that competed in both races.

Comparison of endocrine patterns across two competitions is predicted to result in no significant differences at any point during competition.

A secondary purpose of the present study is to explore relationships between endocrine levels and mental toughness as well as endocrine levels and performance outcomes. Specifically, mental toughness will be explored as a potential variable in explaining competition increases in T and C, whereas levels of T and C will be explored as predictors of performance measured by finish time. Due to the lack of research precedent with mental toughness and hormone levels and the mixed research with hormone levels and performance outcomes, no specific hypotheses are made regarding these variables. Thus, the nature of these analyses will be strictly exploratory.

## CHAPTER 3: Method

### *Participants*

16 male and 22 female, collegiate cross-country runners provided saliva samples for the present study during an early season competition. Athletes were members of a highly ranked Division III NCAA program. The sample was predominately Caucasian in ethnic background and approximately 18-24 years of age. Athletes were informed that participation was voluntary and would have no bearing on running rank or status with coaches.

### *Measures*

*Saliva samples and hormone assays.* Cortisol and testosterone levels were assessed through saliva samples and hormone assays. Approximately 5ml of saliva from each participant was collected in a 20ml plastic vial. Vials were stored at -20°C and sent to a separate lab for hormone assay.

*Oral contraceptive use.* Prior to the day of competition, female participants were also asked to fill out a written questionnaire that asked whether or not they were currently taking oral contraceptives (OCs) or some other form of birth control. Research has demonstrated that OC use decreases serum testosterone (e.g.; Coenen, Thomas, Borm, Hollandars, & Rolland, 1996, Wiegratz, Jung-Hoffman, & Kuhl, 1995). Thus, it is customary in research with T to gather this information as it may account for variability in T among women.

*Mental Toughness in Sport Questionnaire (MTSQ).* The MTSQ is a 50-item measure developed by Harmison, Sims, and Virden (2008) to assess the values, attitudes, beliefs, emotions, and self-regulation skills associated with mental toughness in athletes.



Participants were asked to rate each item on a 7-point likert scale (1 being “strongly disagree” and 7 being “strongly agree”) based the degree with which that item “accurately reflects your thoughts and feelings about yourself.” There are 5 subscales consisting of 10 items each. Table 1 provides these subscale names, a description of their meaning, and a sample item. The MTSQ is theoretically grounded in a social-cognitive framework for understanding mental toughness in sport (Harmison, 2011), and preliminary evidence suggests that the MTSQ is a valid and reliable (Cronbach’s alpha = 0.89 for all 50 items; subscale alphas range from .69-.83) measure of mental toughness in athletes (Harmison et al., 2008). It is theorized that mental toughness as measured by the MTSQ, represents a trait-like feature of personality, no likely no change over short periods of time (Harmison, 2011). Therefore, the proximal timing of the completion of this measure in relation to the actual competition event is not necessary to assume that the mental toughness attributes, measured by the MTSQ, were in effect when data were collected during the competition.

Table 1

*MTSQ subscale names, a description of their meaning, and a sample item*

MTSQ subscale	Description	Example item
Tough Beliefs	The convictions and expectations that mentally tough athletes hold to be true about themselves and the competitive environment.	I believe 100% in my ability to respond successfully to challenging, competitive situations.
Tough Attitudes	The personal constructs that mentally tough athletes have about themselves and their perceptions of the competitive environment.	When I'm tired or in pain during competition, I am able to push through my limits and give a little bit more.
Tough Skills	The plans, strategies, and actions utilized by mentally tough athletes to regulate their thoughts, feelings, and behaviors in competitive situations.	After making a mistake during competition, I quickly forget about the error and mentally let it go.
Tough Values	The motives, goals, and desired outcomes possessed by mentally tough athletes as they attempt to achieve in competitive situations.	To play at my best, it is important that I manage my worry and physical nervousness about my performance.
Tough Emotions	The psychological and physiological feelings states experienced by mentally tough athletes in response to competitive situations.	At demanding or painful times in a competition, I usually feel negative emotions, such as pessimism or frustration (reverse scored).

### *Procedure*

Several days prior to competition, the experimenter met with the team to explain the procedure, obtain consent, and administer the MTSQ. This invitation included an explanation that the data would be coded and stored on a password protected electronic spreadsheet and would thus, not be linked to the contributing participant by name.

On the day of competition, participants were asked to give saliva samples before warm-up, after warm-up, and immediately after completion of the race. Participants were given sugar-free gum (Trident original flavor) to stimulate salivation and a 20-ml plastic vial. They then were asked to chew for 2 minutes and then fill the vial to the 5-ml line

marked on the side, cap the vial, and place it in the designated location in a cooler. Samples were stored at  $-20^{\circ}\text{C}$  within the hour and delivered to a separate site for analysis. One month after the competition, participants were given (via a link in an email) the web address to complete the MTSQ online where they first entered the 4-digit code that linked the survey data to the hormone concentrations. Participants also were reminded at this time that the data would be coded and stored on a password protected electronic spreadsheet and would thus, not be linked to the contributing participant by name.

### *Data Analysis*

Mean scores across all collection periods and percent change from before warm-up to after competition were calculated for cortisol (C) and testosterone (T). Additionally, MTSQ subscale means for Tough Values, Beliefs, Attitudes, Skills, and Emotions were calculated by averaging the item values for each scale (with 10 items per scale). Two female participants were present for the competition and gave saliva samples, but did not race. These participants' values were excluded in all statistical analyses involving T and C. Additionally, one male participant had testosterone values that far exceeded ( $>300$  pg/ml) values of all other members of the team as well as normal population values. Thus, this participant's data was excluded from all relevant analyses.

Descriptive analyses and zero-order correlations among all variables in the study were conducted first in order to visualize general patterns, identify outliers, and observe possible relationships among variables. Female participant's values will be analyzed to determine if there are any major differences between OC users and non-users. If no major differences exist, OC users and non-users will be combined for all remaining analyses. To analyze patterns of change for T and C for men and women at each time

point throughout the competition event a 3 (testosterone) x 2 (gender) mixed ANOVA, with repeated measures on T, and a 3 (cortisol) x 2 (gender) mixed ANOVA, with repeated measures on C, will be conducted. A 3 (testosterone) x 2 (year) and a 3 (cortisol) x 2 (year) repeated measures ANOVA across gender will be conducted to further analyze the endocrine patterns for consistency across time. Next, endocrine patterns will be graphed for men and women with separate lines for the top-7 versus non-top-7 finishers in the race to compare patterns across performance groups. Because only the top-7 finishers for each team were the only members to have their overall finish order count towards the team score, a natural status division (top-7, non-top-7) exists. Simple independent t-tests were conducted where large differences between top-7 and non-top-7 were visible. To further understand how T and C may differentiate by performance, this analysis will be followed-up with two separate hierarchical multiple regressions (one for males and one for females) with endocrine levels at each time point and TxC interaction at each time point as predictors of finish time. A final hierarchical regression with MTSQ subscales predicting competition levels of T and C will be conducted to explore the effect of a psychological variable in predicting competition related changes in physiology.

## CHAPTER 4: Results

### *Descriptive Analysis*

Descriptive statistics for T and C from before warm-up (A), after warm-up (B), and after competition (C), average performance times for men and women, and MTSQ subscale averages are shown in Table 2. Zero-order correlations for these variables are presented in Table 3 for female and male participants.

Simple observation of the mean values in Table 2 appear to suggest that both T and C were relatively stable from before to after warm-up, but made a noticeable increase during competition. Additionally, although men and women participants were similar in cortisol values, men were much higher in testosterone. This is consistent with well-understood gender differences in endocrinology (Edwards et al, 2007). Both male and female athletes in this study appear to have similarly high self-reported mental toughness qualities (average ratings are >5, meaning participants mostly agree that they possess those qualities). Further, both men and women reported the lowest mentally tough attribute to be Tough Emotions. For female athletes in the study, testosterone measured after warm-up, directly prior to competition, was significantly positively correlated with items pertaining to mentally tough attitudes ( $r = .50$ ).

Table 2

*Means and standard deviations for the main variables in the present study by gender for athletes that raced*

	Men (N=15)		Women (N=20)	
	M	SD	M	SD
Testosterone(A)	118.58	42.27	54.18	10.54
Testosterone(B)	108.76	41.54	57.33	12.48
Testosterone(C)	181.49	25.46	82.35	24.37
Cortisol(A)	0.462	0.266	0.498	0.218
Cortisol(B)	0.347	0.176	0.391	0.123
Cortisol(C)	0.850	0.415	0.673	0.343
Performance (sec)	1675	35.43	1181	63.99
MTSQ Beliefs	5.53	0.921	5.36	0.462
MTSQ Attitudes	5.43	0.847	5.26	0.838
MTSQ Skills	5.26	0.798	4.59	0.687
MTSQ Values	5.78	0.742	5.63	0.655
MTSQ Emotions	4.56	0.624	4.21	0.729

*Note.* A = before warm-up; B = after warm-up; C = after competition. Cortisol is measured in  $\mu\text{g}/\text{dl}$  and testosterone is measured in  $\text{pg}/\text{ml}$ . The performance variable for men pertains to an 8 kilometer race and for women, a 5 kilometer race. The MTSQ subscale scores were based on a 7-point Likert scale.

Table 3

*Correlation values of the main variables in the present study for female (below the diagonal) and male (above the diagonal) participants that raced*

	T(A)	T(B)	T(C)	C(A)	C(B)	C(C)	Perf	B	A	S	V	E
Testosterone (A)	--	.48	.19	.54*	.21	-.42	.07	.19	.12	.16	-.08	-.14
Testosterone (B)	.83**	--	.19	.62*	.78**	.26	-.35	-.31	-.11	-.33	-.34	.07
Testosterone (C)	.28	.40	--	.17	-.01	.28	.40	.13	-.21	.02	-.25	.41
Cortisol (A)	.29	.14	-.26	--	.52*	.05	-.06	.03	.26	-.09	.11	.32
Cortisol (B)	.15	.16	-.02	.76**	--	.27	-.43	-.13	.12	-.15	-.16	.18
Cortisol (C)	.17	.14	.61**	.15	.37	--	.00	-.20	-.15	-.28	.01	.27
Performance (sec)	.02	-.13	-.23	.14	.05	-.24	--	.29	.08	.51	.01	.19
MTSQ Beliefs (B)	.09	.28	.04	-.05	.04	-.07	-.14	--	.79**	.95**	.80**	.47
MTSQ Attitudes (A)	.32	.50*	.33	-.16	-.12	.05	-.34	.64**	--	.79**	.78**	.40
MTSQ Skills (S)	.04	-.04	-.34	.37	.15	-.12	.40	-.10	-.06	--	.71	.43
MTSQ Values (V)	.28	.41	.30	-.30	-.29	-.05	-.33	.59*	.75**	-.15	--	.47
MTSQ Emotions (E)	-.17	-.12	-.29	.29	.15	-.18	.00	.39	.19	.39	-.11	--

*Note.* N = 20. A = before warmup; B = after warmup; C = after competition. \*\* Correlation is significant at the .01 level (2-tailed) \*Correlation is significant at the .05 level (2-tailed).

### *Effects of Oral Contraceptive Use*

Of the 20 women that raced, 12 were using oral contraceptives (OC), 1 was using a contraceptive implant, and 7 were not using either. The one participant using a contraceptive implant was omitted from the analysis due to the low sample size. Descriptive statistics for the main variables in the present study by OC use are shown in Table 4. Observation of these values indicate that women not using OCs were higher on all hormone levels, had faster race results, and scored higher on all MTSQ subscales on average. However, these differences were only largely noticeable for testosterone levels. Figure 2 shows the differences in OC users and non-users with 95% confidence intervals and indicates that OC users were significantly lower at the  $p < .01$  level on after warm-up testosterone. Competition related testosterone (C) also appears significantly different for OC users and non-users at the  $p < .05$  level. However, the wide range of the confidence intervals is impacted by the low sample size and the degree of variability within this limited sample.

Thus, two follow-up independent samples t-tests were conducted between OC users and non-users for mean differences in after warm-up (B) and competition-related (C) testosterone. A Bonferroni correction yielded an adjusted alpha of .025. The difference between OC users and non-users on competition-related testosterone (C) was not significant,  $t(17) = 1.934$ ,  $p = .070$ . However, OC users and non-users were significantly different in after warm-up testosterone (B),  $t(17) = 2.868$ ,  $p = .011$ ,  $r^2 = .33$ . Importantly, despite lower levels of testosterone at every collection period, the patterns of change in response to competition appear the same. Due to this and the finding that significant differences do not exist for competition-related testosterone (C) in this

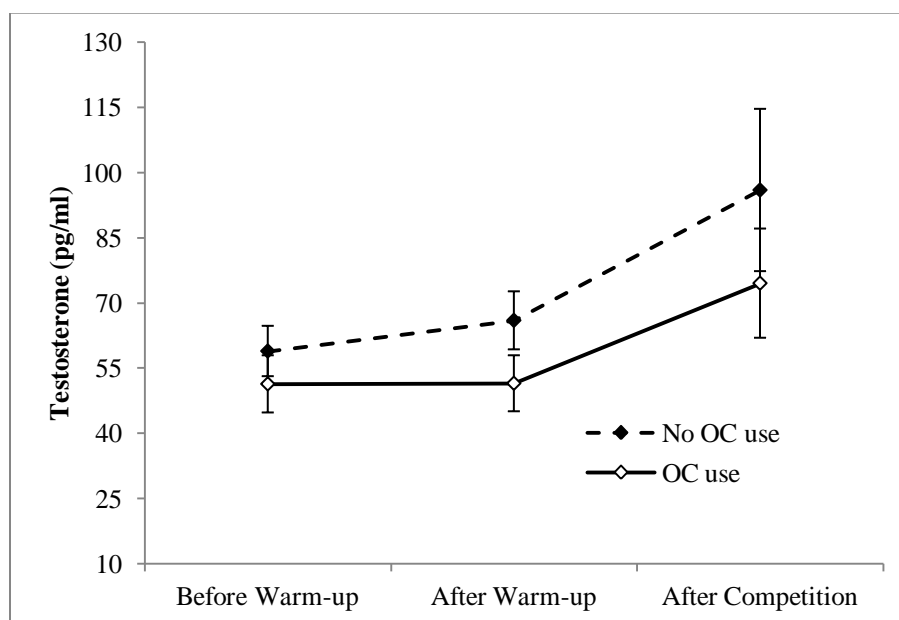
sample, the remaining analyses will be conducted with the combined OC user and non-user sample for women.

Table 4

*Means and standard deviations for the main variables in the present study by OC use*

	Oral Contraceptive Use			
	No ( <i>N</i> = 7)		Yes ( <i>N</i> = 12)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Testosterone (A)	58.87	7.82	51.30	11.63
Testosterone (B)	65.93	9.02	51.44	11.39
Testosterone (C)	95.94	25.22	74.49	22.22
Cortisol (A)	0.51	0.24	0.49	0.22
Cortisol (B)	0.40	0.13	0.38	0.13
Cortisol (C)	0.76	0.41	0.61	0.32
Performance (sec)	1166	44.64	1184	73.62
MTSQ Beliefs	5.40	0.46	5.37	0.50
MTSQ Attitudes	5.49	0.55	5.28	1.04
MTSQ Skills	4.56	0.76	4.53	0.56
MTSQ Values	5.84	0.59	5.57	0.74
MTSQ Emotions	4.34	0.67	4.13	0.85

*Note.* A = before warmup; B = after warmup; C = after competition.



*Figure 1.* Mean differences in testosterone levels for OC users (*N*=12) and non-users (*N*=7). Error bars indicate 95% confidence intervals.



### *Competition-related Endocrine Profiles*

*Is there a competition pattern for T and C and is it the same for men and women?*

Salivary levels of T and C before warm-up, after warm-up, and after competition for male ( $N=15$ ) and female ( $N=20$ ) athletes that raced and female athletes that did not race ( $N=2$ ) are shown in Figures 2 and 3 respectively. Ninety-five % confidence intervals suggest that although males were significantly higher on testosterone at every time point than females, both male and female athletes that raced demonstrated a significant increase in both T and C relative to the race, but not warm-up. Confidence intervals are not shown for women who did not race due to the low sample size. However, mean values are included as a reference for non-competing values of T and C. To further understand these effects, a 3 (testosterone) x 2 (gender) mixed ANOVA, with repeated measures on T, and a 3 (cortisol) x 2 (gender) mixed ANOVA, with repeated measures on C, were used to examine the T and C levels across the three designated time points during competition for male and female athletes.

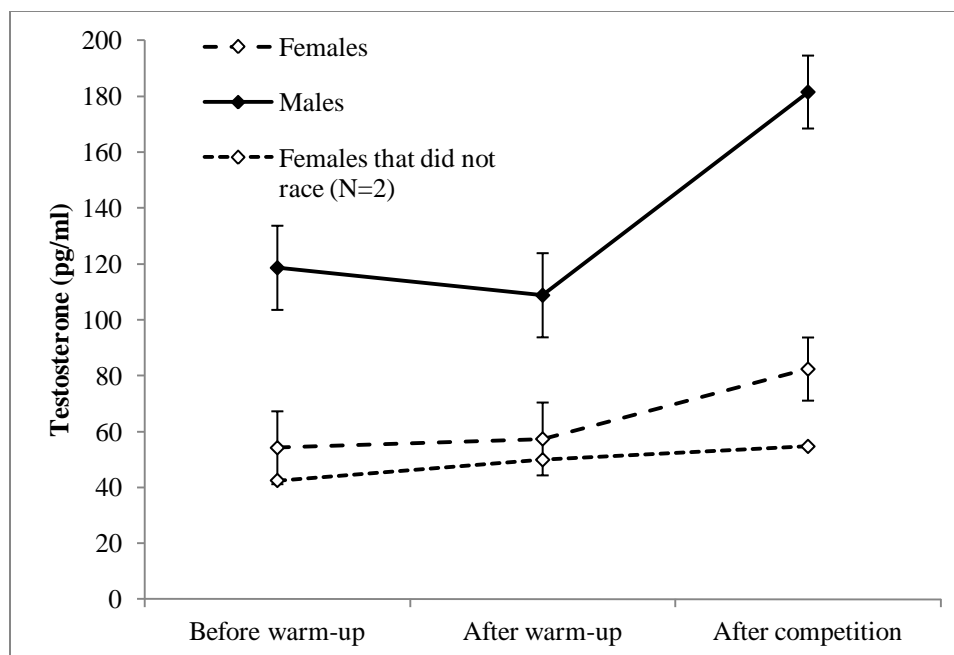


Figure 2. Mean differences in salivary levels of T before warm-up, after warm-up, and after competition for male ( $N=15$ ) and female ( $N=20$ ) athletes that raced and female athletes that did not race ( $N=2$ ). Error bars indicate 95% confidence intervals.

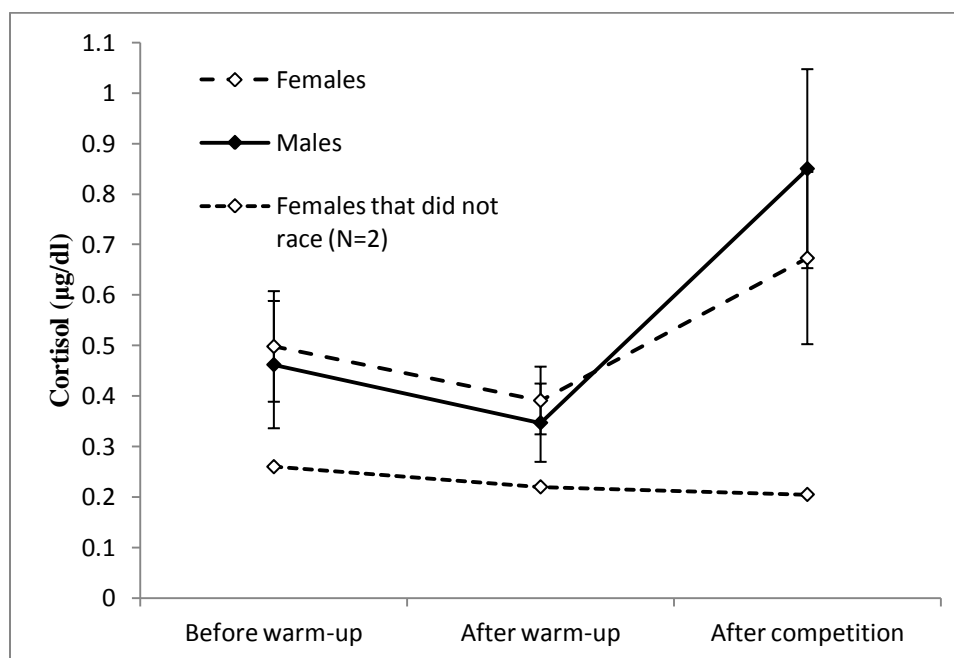


Figure 3. Mean differences in salivary levels of C before warm-up, after warm-up, and after competition for male ( $N=15$ ) and female ( $N=20$ ) athletes that raced and female athletes that did not race ( $N=2$ ). Error bars indicate 95% confidence intervals.

Results from the mixed ANOVA with repeated measures on testosterone revealed that, regardless of gender, there was a significant main effect for levels of T across the three time points,  $F(2,66) = 49.16, p < .001, \eta_G^2 = .517$ . Contrasts revealed that although after warm-up salivary T was not significantly elevated from before warm-up levels of T, after competition T was significantly elevated from both before,  $F(1,33) = 59.89, p < .001, \eta_G^2 = .575$ , and after warm-up,  $F(1,33) = 72.43, p < .001, \eta_G^2 = .609$ , levels for the combined sample of men and women. There was also a main effect for gender,  $F(1,33) = 850.31, p < .001, \eta_G^2 = .48$ , such that men were significantly higher in T than women at every time point. Interestingly, results from this analysis also revealed a significant interaction between levels of salivary T and gender,  $F(2,66) = 10.04, p < .001, \eta_G^2 = .179$ . This indicates that differences in men and women's salivary levels of T varied at different time points. To break down this interaction, contrasts were performed comparing before warm-up T to after warm-up T and after competition T across male and female athletes. This simple effects analysis revealed that the interaction was only significant when comparing male and female salivary T levels from after warm-up to after competition,  $F(1,33) = 17.26, p < .001, \eta_G^2 = .278$ . Looking at Figure 2, this finding suggests that although men decrease slightly and women increase slightly during warm-up, this trend is not significantly different across gender. However, despite significant race related increases in T for both men and women, this significant interaction suggests that male athletes experienced a more pronounced elevation in salivary T specific to the actual race than did female athletes. It remains uncertain, however, whether this finding is due to gender differences in the competition profiles of T for men and women or due to the difference in race time and distance (as men completed a 8k race in an average of time of

27 minutes and 55 seconds, whereas women completed a 5k race in an average time of 19 minutes and 41 seconds).

Results from the mixed ANOVA with repeated measures on C revealed that, regardless of gender, there was a significant main effect for levels of C across the three time points,  $F(2,66) = 24.54, p < .001, \eta_G^2 = .362$ . Contrasts (and graphical analysis of Figure 3 for directionality) revealed that across gender C significantly decreased during warm-up,  $F(1,33) = 12.05, p = .001, \eta_G^2 = .154$ . Like T, after competition C was also significantly elevated from both before,  $F(1,33) = 15.06, p < .001, \eta_G^2 = .276$ , and after warm-up,  $F(1,33) = 41.34, p < .001, \eta_G^2 = .496$ , levels for the combined sample of men and women. There was no main effect for gender or interaction between cortisol and gender indicating that men and women were not significantly different in salivary C across all three time periods or within any time period.

*Is the competition pattern for T and C replicated across time?* Seven female and four male participants competed in the same collegiate race, under similar conditions, one year apart. Mean salivary levels of T before warm-up, after warm-up, and after competition for female and male athletes that raced by year (2010 vs. 2011) are shown in Figures 4 and 5 respectively. Additionally, mean salivary levels of C before warm-up, after warm-up, and after competition for female and male athletes that raced by year (2010 vs. 2011) are shown in Figures 6 and 7 respectively. Ninety-five % confidence intervals are not shown due to low sample sizes. Descriptive analyses of these graphs indicate that these athletes show clear similarities in endocrine patterns across time. That is, both males and females at both races demonstrate a consistent and substantial increase in race/actual competition related T and C. A 3 (testosterone) x 2 (year) and a 3 (cortisol)

x 2 (year) repeated measures ANOVA across gender were conducted to further analyze the endocrine patterns across time. T and C levels were collapsed across gender for the present analysis due to the low number of participants that participated in both races.

Supporting results collected from the larger sample observed at the 2011 race, results from the repeated measures ANOVAs with salivary T levels and C across year revealed that there was a significant main effect for T,  $F(2,20) = 12.94, p = .003, \eta_G^2 = .443$ , and C,  $F(2,20) = 6.39, p = .020, \eta_G^2 = .369$ . Also in agreement with aforementioned results for the larger sample, contrasts revealed that there was no significant effect for T or C across warm-up, but there was a significant difference in salivary T,  $F(1,10) = 11.97, p = .006, \eta_G^2 = .406$ , and C  $F(1,10) = 9.07, p = .013, \eta_G^2 = .443$ , between after warm-up and after-competition. Again, this supports the notion that there is a substantial rise in both T and C specific to the actual competition, but not warm-up. Importantly, there was no main effect for year or interaction between T or C and year indicating that the competition related pattern of salivary T and C was similar across the male and female athletes that competed in both races. This finding uniquely contributes to the understanding of the competition related endocrine profile for T and C as it demonstrates the same effect across time for the same group of runners competing under similar conditions.

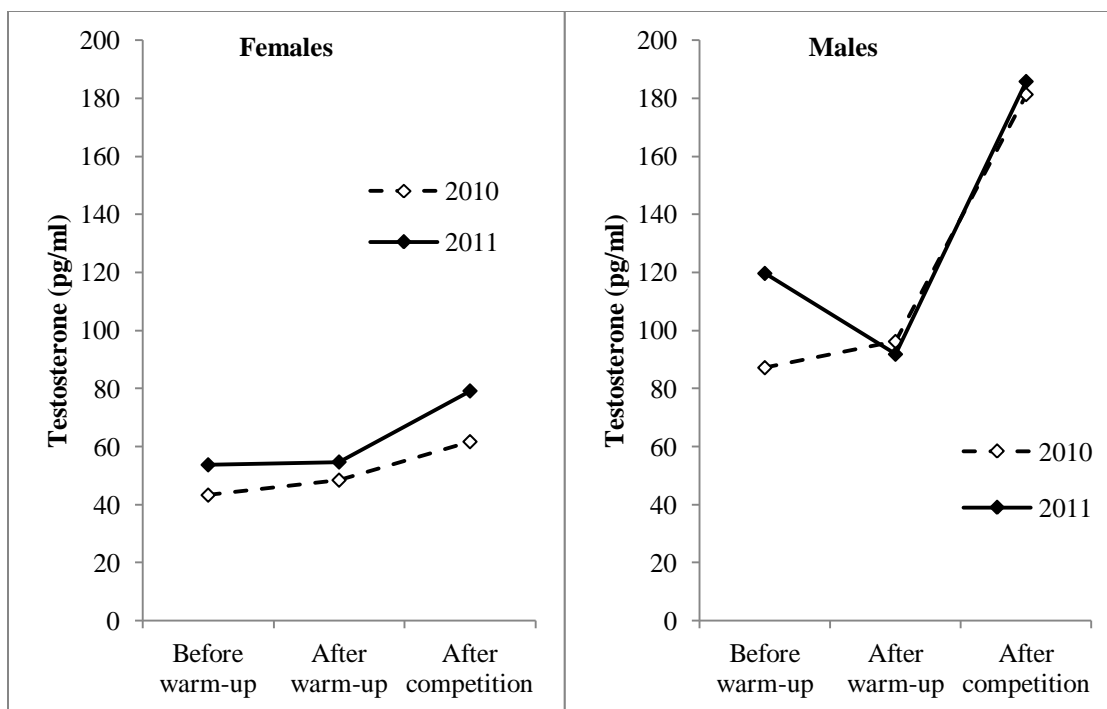


Figure 4. Mean differences in salivary levels of T before warm-up, after warm-up, and after competition for female ( $N=7$ ) and male ( $N=4$ ) athletes that raced by year.

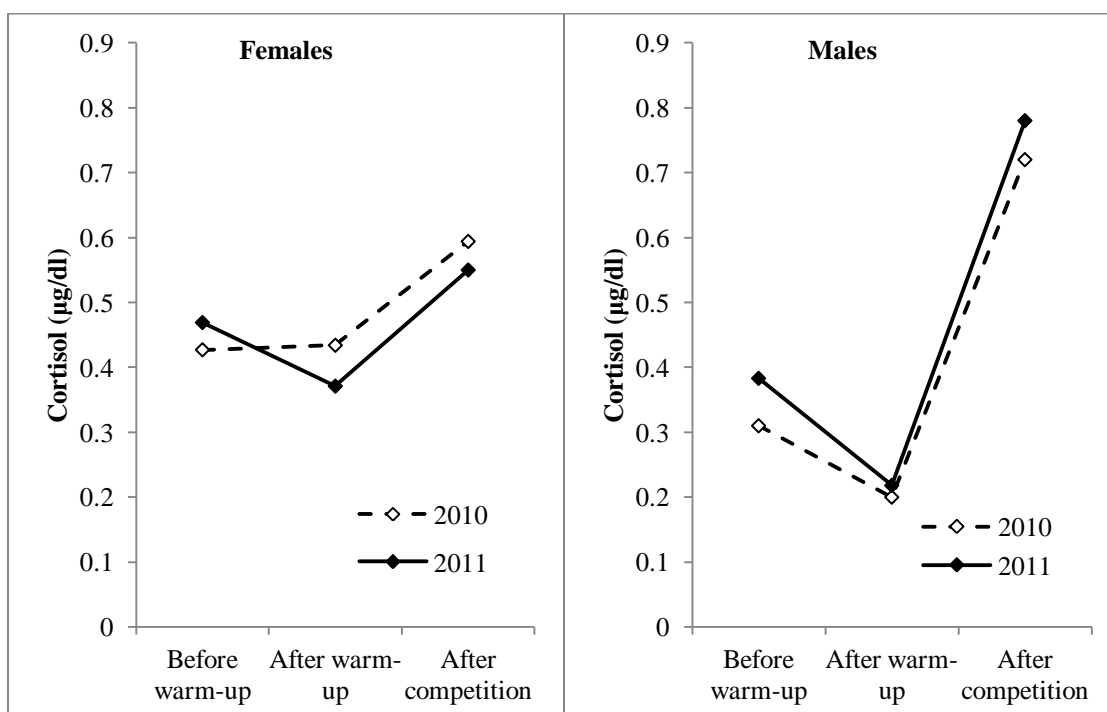


Figure 5. Mean differences in salivary levels of C before warm-up, after warm-up, and after competition for female ( $N=7$ ) and male ( $N=4$ ) athletes that raced by year.

*Is the competition pattern for T and C the same for runners that contributed to the team score and those that did not?* In both the men's and women's races, only the top seven finishers (those with faster performances) contributed to the overall team score. Team scores in this race were calculated by summing the overall finish order (place among all athletes in the race) of the first seven finishers on each team. For women that raced, the top seven had an average 5k finish time of 18:40 ( $SD= 10$  seconds) and the remaining 13 had an average finish time of 20:17 ( $SD=52$  seconds). For men that raced, the top six (the seventh place male did not participate in the study) had an average 8k finish time of 27:23 ( $SD=16$  seconds) and the remaining 10 had an average finish time of 28:15 ( $SD=26$  seconds). Figures 6 and 7 show the mean salivary levels of T and C, respectively, for both female and male athletes that raced grouped by top seven finishers and non-top seven finishers. Several interesting differences between scoring members and non-scoring members of each team stand out graphically and will be explored with further analyses.

First, the top seven women appear to have a more dramatic rise in T relevant to warm-up as well as competition (Figure 6). A repeated measures t-test was used analyze this difference, rather than an ANOVA as previously demonstrated, due to the low sample sizes for each group. As such, a repeated measures t-test revealed that a significant increase in salivary T from before- to after warm-up for the top-seven racers,  $t(6) = 6.65$ ,  $p = .42$ ,  $r^2 = .88$ , but not for the remaining 13. This suggests that the more elite members of the team may exhibit a greater anticipatory rise in T in preparation for competition. Second, Figure 7 suggests that the top seven women are lower on both before- and after warm-up C. An independent t-test for both time points revealed that the

top-seven were significantly lower than the remaining members of the team in both before,  $t(19) = 4.697$ ,  $p = .044$ ,  $r^2 = .53$ , and after warm-up C,  $t(19) = 4.812$ ,  $p = .042$ ,  $r^2 = .55$ . The top six finishers for the men's team are lower on C than the remaining nine team members before warm-up only, but this difference was not found to be significant. No other differences between the top-6 men and the remaining team members appear. The initial trend among both men and women (i.e., lower C among the higher status members of the team) may suggest that perhaps higher levels of cortisol prior to or in anticipation of competition serves less a functional benefit for performance during competition. Unexpectedly, the top six members of the men's team were actually lower than the remaining nine in salivary T at every time point, however, these differences were also non-significant. Low sample sizes among groups may have impacted the significance of findings regarding differences in scoring and non-scoring members of the team.



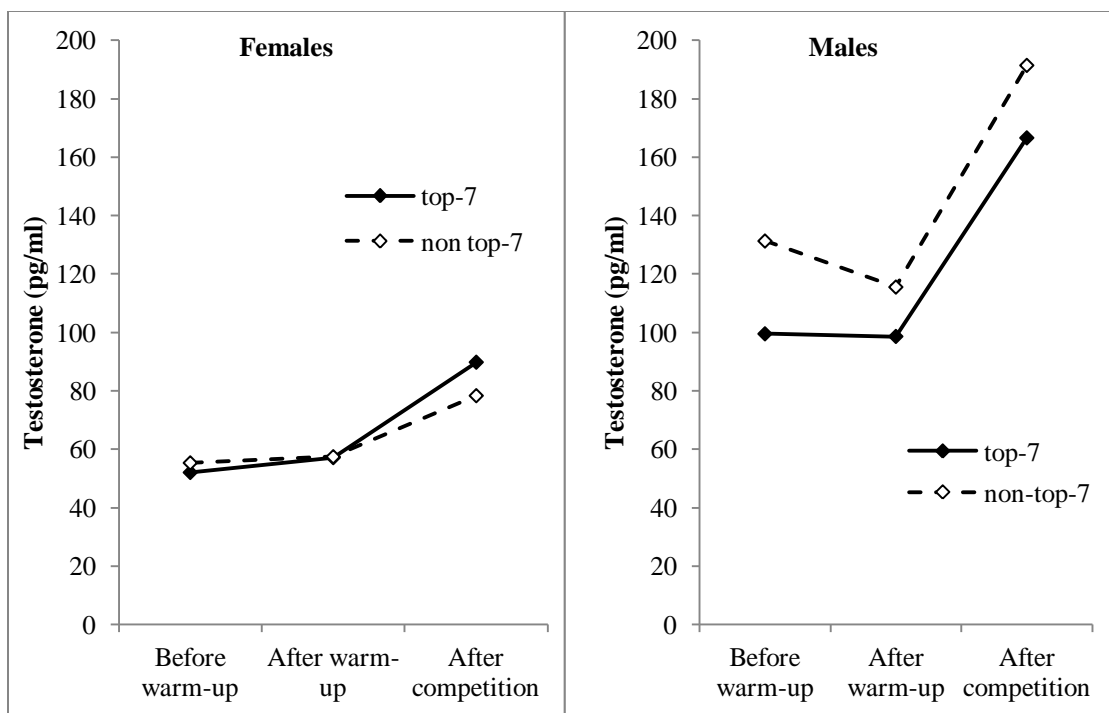


Figure 6. Mean differences in salivary levels of T before warm-up, after warm-up, and after competition for female and male athletes that raced grouped by top seven finishers and non-top seven finishers. Women, non top-7  $N = 13$ ; Men, non top-7  $N = 9$

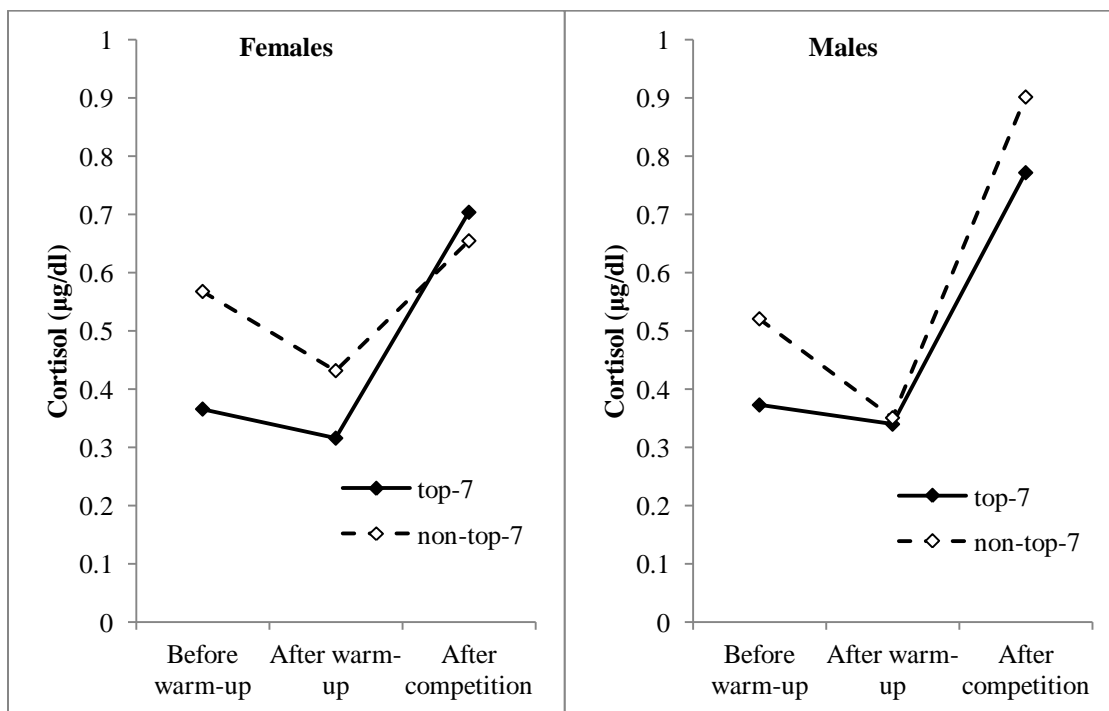


Figure 7. Mean differences in salivary levels of C before warm-up, after warm-up, and after competition for female and male athletes that raced grouped by top seven finishers and non-top seven finishers. Women, non top-7  $N = 13$ ; Men, non top-7  $N = 9$

### *Predicting Finish Time with T and C Levels*

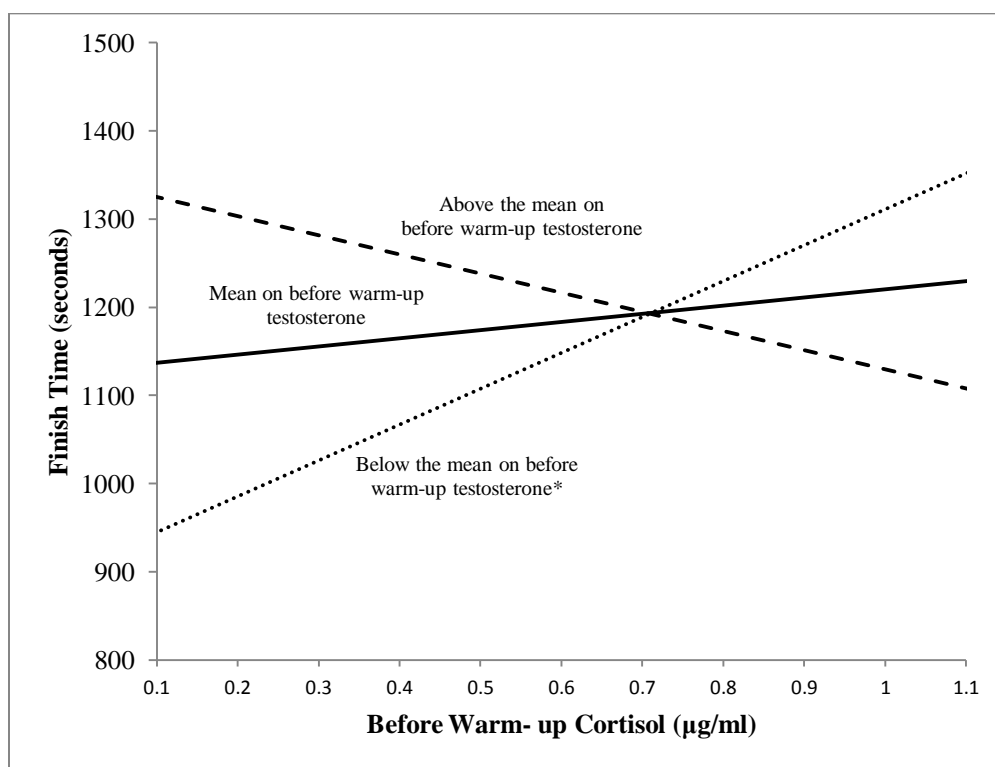
Results from the previous section indicating the existence of performance based differences in anticipatory, but not actual competition levels of T or C warrant further investigation. The outcome variable for performance is the athletes finish time, the amount of time in seconds that each member of the team completed the race. To explore the effect of T and C on performance, males and females were analyzed separately as they competed in separate races of different length. The average 8k time for males was 27:55 ( $SD = 35$  seconds) and the average 5k time for females was 19:41 ( $SD = 66$  seconds). Initial observation of correlation values in Table 3 indicate that, among females, there is a negative relationship between finish time and both T ( $r = -.23$ ) and C ( $r = -.24$ ) measured after competition. This indicates that faster finish times (relative better performances) are associated with higher levels of T and C during competition. In contrast, observation of correlation values in Table 3 indicate that, among males, there is a positive relationship between finish time and T ( $r = .40$ ) measured after competition and no relationship between finish time and C ( $r = 0$ ) measured after competition. This indicates that faster times are associated with relatively lower T during competition. Among males there also appeared to be a meaningful relationship between finish time and T and C measured after warm-up. Specifically, there was a negative relationship between finish time and both T ( $r = -.35$ ) and C ( $r = -.43$ ) measured after warm-up such that faster finish times were associated with higher after warm-up/directly prior to competition levels of T and C.

Two separate hierarchical regression analyses were conducted, one for both the female and male participants, to assess the relationship between salivary T and C before

warm-up, after warm-up, and after competition and finish time. Predictors entered into the model at step one of the analysis included raw values for T and C at each time point. Step two included the interaction of T and C at each time point. Interaction variables were calculated by centering T and C to reduce multicollinearity according to Aiken and West (1991). For the female participants, results showed that neither the model containing raw values for T and C nor the combined model including the interaction variables were a significant predictor of the finish time. Although neither of the overall models significantly predicted performance, there was a significant effect for the interaction of T and C for saliva samples collected before warm-up,  $b = -35.39$ ,  $t = -2.71$ ,  $p = .022$ , 95% CI = -69.5 to -6.3. This indicates that at baseline pre-competition levels the effect of T on finish time is dependent on C. Also, because the interaction term is negative, as C decreases there is a more positive relationship between T and finish time.

This interaction is visually demonstrated by the non-parallel slopes seen in Figure 8 that shows the regression of before warm-up C on finish time at three levels before warm-up T. These slopes were determined from simple regression equations for the relationship between pre-warm-up C and finish time at the mean for pre-warm-up T (54.18), one standard deviation below (43.64), and one standard deviation above (64.72) the mean T. The simple regression slope for C on finish time was only statistically significant at one standard deviation below the mean on T; thus, the relationship becomes more positive as T levels decrease (see Table 5). This indicates that high cortisol before warm-up has a negative impact on performance (slower finish times) only if T is relatively low. At the mean for before warm-up T, the relationship between pre warm-up C and finish time is also positive, however, at one standard deviation above the mean on

T the relationship is negative (higher C resulted in faster times). However, the slopes of these relationships were not statistically significant. Although these slopes are non-significant, this reversal of the effect of before warm-up C on finish time depending on T is meaningful and clearly demonstrated in Figure 8. Collectively this suggests that among the women athletes sampled, high levels of both T and C before warm-up provided a more adaptive state for performance outcomes in anticipation of competition, whereas high C without relatively high values of T resulted in a less adaptive state for performance outcomes. The same analysis of the male participants resulted in no significant predictors of finish time.



*Figure 8.* Regression of finish time on before warm-up salivary C at three levels of before warm-up salivary T for females. \* indicates that the simple slope for C at that level of T is significant.

Table 5

*Simple regression equations of finish time and before warm-up salivary C at three levels of before warm-up salivary T for females.*

Level of before warm-up T	Simple Regression Equation	SE of <i>b</i>	<i>t</i> -test	95% CI of <i>b</i>
-1 SD (43.64)	Time' = 484.7(C) + 1120	209.5	2.31*	18 to 951
Mean (54.18)	Time' = 111.8(C) + 1176	129.6	0.86	-177 to 400
+1 SD (64.72)	Time' = -261.2(C) + 1233	166.0	-1.57	-631 to 108

\**p* < .05

*Exploring the Role of Mental Toughness in Accounting for Competition-related Increases in T and C*

Given the availability of data regarding a psychological variable relevant to competition (i.e., mental toughness), it is possible to conduct an exploratory analysis to investigate mental toughness as a possible contributing factor to the competition related elevations in T and C found in the present study. Correlation values, shown in Table 3, suggest that the correlation between testosterone measured after warm-up and after competition and several of the MTSQ subscales actually reversed in direction for male and male athletes.

Thus, two separate hierarchical regression analyses were conducted, one predicting competition T and one predicting competition C, to assess the relationship between salivary competition rises in T and C and mental toughness attributes. Predictors entered into the model at step one of the analysis included after warm-up T (for the analysis involving T) and C (for the analysis involving C) and gender to control for before competition T and gender differences in T. Step two included the variables for each of the MTSQ subscales (i.e., Tough Beliefs, Attitudes, Skills, Values, and Emotions). Step three added the interaction variables for each of the mental toughness

subscales by gender. Interaction variables were calculated by centering values of the mental toughness subscales to reduce multicollinearity according to Aiken and West (1991). Gender was coded 0 for females and 1 for males.

Results showed that the overall combined model including the after warm-up T, gender, the mental toughness attributes, and the interaction terms was a significant predictor of after competition salivary T ( $R^2 = .911$ ,  $F(12, 25) = 11.10$ ,  $p < .001$ ). Thus, the control variables, predictors, and the interaction terms combined to significantly predict or explain differences in competition-related T. The addition of interaction term did add a significant amount of variance to the model ( $R^2_{\text{change}} = .104$ ,  $F_{\text{change}}(5, 13) = 3.04$ ,  $p = .049$ ). This indicates that the effect of the mental toughness attributes on competition levels of T is dependent on gender and gender dependent interaction explains an additional 10% of the variance in competition levels of T after controlling for T just prior to competition. However, as shown in Table 6, none of the individual predictors or interaction terms alone accounted for a significant amount of variance in competition related T. Despite the lack of statistical significance, two of the interaction terms, beliefs\*gender and values\*gender, approach significance. The same regression analysis was conducted predicting competition related levels of salivary C, but no significant relationships were found. Together these findings provide an intriguing point for further discussion as it suggests that there may be some value in further exploring the role on mental toughness in predicting competition physiology (for T in particular).

Table 6

*Regression analysis predicting competition related T from after warm-up T, gender, mental toughness attributes and the interaction between mental toughness attributes and gender.*

Step and Predictor variables	R <sup>2</sup>	ΔR <sup>2</sup>	b	β	95% CI of b
Step 1	.800*	.800*			46.62 to 95.40
After warm-up T			.164	.113	-.177 to .505
Gender			93.34	.824	66.62 to 120.06
Step 2	.807*	.007			
After warm-up T			.186	.129	-.236 to .609
Gender			94.47	.834	56.99 to 131.94
MTSQ Beliefs			6.63	.083	-28.17 to 41.43
MTSQ Attitudes			.576	.009	-24.18 to 25.33
MTSQ Skills			-3.37	-.041	-32.10 to 25.36
MTSQ Values			.920	.012	-30.37 to 32.21
MTSQ Emotions			-2.88	-.037	-23.49 to 17.72
Step 3	.911*	.104*			
After warm-up T			.004	.003	-.417 to .424
Gender			114.25	1.01	69.32 to 159.18
MTSQ Beliefs			-14.79	-.185	-57.66 to 28.08
MTSQ Attitudes			12.10	.185	-13.68 to 37.89
MTSQ Skills			10.84	.133	-24.00 to 45.68
MTSQ Values			11.33	.146	-22.97 to 45.62
MTSQ Emotions			-9.58	-.124	-33.28 to 14.13
MTSQ Beliefs x gender			77.94**	.831**	-1.68 to 157.55
NTSQ Attitudes x gender			-20.63	-.198	-66.59 to 25.33
MTSQ Skills x gender			-56.18	-.532	-141.94 to 29.59
MTSQ Values x gender			-52.61**	-.434**	-109.59 to 4.37
MTSQ Emotions x gender			31.83	.209	-14.15 to 77.80

*Note.* b = raw score regression coefficient, \* $p < .05$  \*\* $p < .07$

## CHAPTER 5: Discussion

Results from the present study highlight the important and intricate role of hormones, namely T and C, in competition. Specifically, results most notably demonstrated the not only statistically significant, but also substantial rise in salivary levels of both T and C during actual competition for both male and female endurance athletes as predicted. Although some portions of the sample also demonstrated a significant, but less substantial rise in T during warm-up the competition effect for T and C appears uniquely distinct from warm-up levels of exercise or psychological anticipation. Additionally, this elevation in T and C due to competition was replicated across time for a sample of cross country runners that competed in the race, under similar conditions, one year apart. Thus, the main result from the present study is an extension of previous research by demonstrating a competition effect for T and C among endurance athletes and for the same group of athletes at two separate, but similar competitions.

Further, the use of cross country runners in this study allowed for an analysis of T and C levels by performance. Results showed that although competition related levels of T and C did not predict performance, a pre-competition (before warm-up, specifically) interaction between T and C was predictive of finish time for the members of the women's team. This finding has important implications for the psychological components of each of these hormones in relation to promoting adaptive coping mechanisms in anticipation of competition. The individual role of psychological and physical demands of the actual competition (e.g., psychological stress or increased physical intensity) in generating the competition elevations in T and C cannot be determined by the present study. However, an initial exploration of mental toughness in



sport revealed that mentally tough beliefs in particular (i.e., one's convictions and expectations about ability), may offer some explanation for competition elevations in T differentially for men and women. Importantly, this exploratory analysis presents interesting possibilities for the use of psychological variables such as mental toughness in understanding why competition uniquely activates or results in a considerable change in physiology.

#### *Competition and Pre-competition Patterns of T and C*

As hypothesized, results demonstrated a large elevation in both T and C during a collegiate cross-country competition for both male and female athletes. The substantial rise in T and C during competition previously has been demonstrated in teams sports (women's volleyball and tennis, Edwards & Kurlander, 2010; women's rugby, Bateup et al., 2002), but not among endurance athletes that compete more individually. The present study also is the first demonstration of similar patterns of T and C before and after warm-up and after competition for the same group of athletes competing under similar conditions, one year apart. This finding may suggest that endocrine patterns leading up to and during competition are not highly circumstantial and further, likely represent a generalized and autonomic pattern of responding to competition.

Results further contribute to the literature on behavioral endocrinology by demonstrating a competition elevation for both men and women in the same competition task. This contrasts with gender differences found by Kivlighan et al. (2005) that indicated a competition related increase in T for men, but not women during a competitive rowing task. This discrepancy may lie in the nature of the competitive task. In the Kivlighan et al. (2005) study, the competition was during practice and between

members of the same collegiate rowing team to establish rank based on performance. The competition in the present study was an inter-collegiate cross-country race in which the athletes competed against members of other collegiate teams in a more traditional competition style. Results from the present study did, however, show a more dramatic rise in T for men during competition, but the nature of this effect remains uncertain given the difference in length and average finish time of the men's and women's races (with men running further and competing for longer). It is possible that salivary samples collected after the race reflects during competition states that were more advanced (from having competed longer at that point) for men.

Contrary to a hypothesized anticipatory effect, neither T nor C was significantly elevated from before to after warm-up for the total sample of male and female athletes. In fact, C actually decreased for both men and women leading up to competition. However, previous studies have shown a significant rise in T leading up to competition (e.g., Bateup et al., 2002; Booth et al., 1989; Edwards & Kurlander, 2010). Previous research on an anticipatory effect for C is less consistent. Although some researchers have shown that C does noticeably elevate leading up to competition compared to rest days and time periods earlier in the day (Alix-Sy et al., 2008; Bateup et al., 2002; Booth et al., 1989; Salvador et al., 2003), the present study and Edwards and Kurlander (2010) show that, within an hour of competition, C does not significantly change (and in the present study, C actually decreased slightly from before- to after warm-up as competition grew closer). Lack of a true baseline such as rest day levels of T and C in the present study may have limited the ability to capture a general anticipatory effect for T or C, as

physiology directly prior to warm-up, rather than a neutral day, may reflect an already achieved anticipatory state.

Despite inconsistent findings, there is a need to explore anticipation patterns of T and C further. Experiencing a rise in T or C prior to engaging in a competition may have important adaptive effects in preparing for the mental and physical demands of competition (Salvador et al., 2003). For example, high levels of both T and C in the bloodstream at the onset of competition could result in more immediate metabolism of protein and fat to generate energy during competition (Borer, 2003). Prior to competition, T and C may play a role in psychological preparation for the match to come. For example, Mehta and Josephs (2006) showed that a rise in T prior to engaging in a competition predicted willingness to engage in a competitive task. Again, C presents a more complicated psychological portrait. Although, a preparatory rise in C may, for example, be related to bonding and social affiliation among teammates prior to competition (Kivlighan et al., 2005), C is also an index of psychological stress and at very high levels, may inhibit cognitive function (Erickson et al., 2003).

Because an anticipatory rise in T and perhaps C may result in an improved mental and physical state upon entering into competition, it is possible that a preparatory effect may be seen largely among more elite or well-trained performers. This suggests that perhaps an anticipatory effect may occur only in relation to adaptive pre-competition state and may not appear for athletes with less adaptive preparatory responses. Results from the present study show some evidence to support this notion. Among the female athletes, the top seven finishers (i.e., those that contributed to the team score) demonstrated a greater increase in T during warm-up and were lower on pre-competition

levels of C than females who did not finish in the top seven. This indicates that an anticipatory rise in T and low levels of C that do not elevate leading up to competition may be positively related to more elite performances in a cross-country race. Further analysis showed that prior to beginning warm-up, female athletes demonstrated a significant interaction between T and C in predicting finish times such that lower C predicted faster finish times only at low levels of T. Taken together, results suggest that prior to warm-up, and thus, prior to engaging in physical activity, levels of C and T are dependent when predicting race performance. Overall, relatively lower C before competition appears to be most adaptive for performance, particularly when T is also low prior to warm-up. However, a rise in T, regardless of baseline levels may also have adaptive outcomes for performance as suggested by the anticipatory rise seen in the top-seven female cross-country runners in the present study.

Previous research supports the notion that lower levels of cortisol before competition are associated with better performance or performance/skill-based status. Similar to the present study's top-7 versus non-top-7 distinction, Booth et al. (1989) showed that the top seeded tennis players on a team had lower C prior to a singles match, but this was not related to winning or losing. Filaire et al. (2009) further showed that losers of a singles tennis match were higher on pre-competition C than winners. For losers of the match, C also increased as competition drew nearer. Interestingly this study also demonstrated that match losers, in addition to being higher in C, were also higher in cognitive and somatic anxiety than winners providing a psychological basis for the detriments of C on performance (Filaire et al., 2009). Anxiety may inhibit optimal functioning in a sport competition setting by allowing negative thoughts and emotions to

prevent goal-oriented focus and self-confidence in addition to disrupting body strength and composition (Gould, Greenleaf, & Krane, 2008). Sport psychologists have long suspected and provided theoretical and self-report evidence to suggest that psychological states, such as anxiety, prior to competition may actually impact performance during competition (Gould et al., 2008). Importantly, findings from the present study provide physiological evidence that pre-competition states may impact performance (also supported by Filaire et al., 2009). The association of psychological stress with a physiological marker (i.e., cortisol) in predicting performance demonstrates a notable mind-body interaction with valuable implications for behavior in a sport competition setting.

However, the aforementioned interaction between pre-warm-up T and C was only demonstrated among female athletes. Further, it is important to note that male and female athletes do show some differences in pre-competition and competition patterns. For example, the present study showed that male and female athletes show non-congruent endocrine patterns during warm-up and then, during competition, men show a more dramatic rise in T. Although, baseline differences in T for men and women are different due to substantial contributions from the testes in men. However, differences in T and C fluctuations in preparation for competition for male and female athletes are largely unexplained. Perhaps socially, men and women interact differently with teammates prior to competition. Some research suggests that interacting socially with someone of the opposite sex results in rapid elevations of both T and C for both men (Roney, Lukaszewski, Simmons, 2007) and women (if the man is perceived as attractive and the women was not taking oral contraceptives) (Lopez, Hay, Conklin, 2009). Before and

after warm-up the men's and women's cross-country teams sampled were conjugating together in a common area. Given that a majority of women were taking oral contraceptives and thus, not influenced by social interactions with men, gender differences in pre-competition patterns for men and women may have resulted from a discrepancy in how each group responded physiologically to interactions with the opposite sex.

Additionally, it is also possible that men and women have differential coping mechanisms in response to the psychological demands of competition. The MTSQ results show that male and female athletes have opposite relationships between several of the mental toughness attributes and warm-up hormone levels. For example, after warm-up T was positively related to toughness attitudes ( $r = .50$ ) and values ( $r = .41$ ) for females but negatively for males (attitudes,  $r = -.11$ ; values,  $r = -.34$ ). Further exploratory analysis showed that competition related levels of T were explained by the interaction of mental toughness attributes and gender. Specifically, mentally tough beliefs (i.e., one's convictions and expectations about ability) may be the most important mental toughness attribute in predicting competition levels of T differentially for male and female athletes. Although previous research has demonstrated a relationship between mental toughness and performance (Clough, Earle, & Sewell, 2002; Thomas, Schlinker, & Over, 1996) as well as mental toughness and perceived exertion (Clough & Earle, 2002), there are no known previous demonstrations of a relationship between mental toughness and T elevations during competition. T elevation during competition has many adaptive functions both physically (e.g., muscle strength, Kraemer & Spiering, 2006) and psychologically (e.g., willingness to compete, Carré & McCormick, 2008). Thus, a

connection between T and mental toughness would have powerful implications for the importance of this construct in sport. Given that the relationship observed in the current study was not strong, future research will be necessary to fully understand how mental toughness and T relate, particularly depending on gender.

This initial exploratory evidence that a gender dependent psychological variable can actually explain competition elevations in T is a fascinating prospect. Although competition is assumed to have both physical and psychological demands, the physical stress of competing seems more apparent. Further, the importance of psychological variables in sport are valued in achieving optimal performance (Harmison & Casto, 2012), but the physiological data to support their relevance during competition have been sparse.

#### *Functional Considerations*

The findings of trends in T and C in response to various pre-competition and competition states may offer important clues to their physiological basis and raises a number of interesting questions. What is their origin? Does the presence of one impact the presence of the other? Does the origin of or relationship between T and C differ before versus during competition? How does the physiology of blood versus saliva impact their concentrations? Although the present study cannot address these questions directly, previous endocrinological research in combination with the current findings present an opportunity for relevant speculation.

In regards to origin, it is well-understood that the HPA axis results in the release of cortisol and the HPG axis results in the release of testosterone, in general. Although exercise induced elevations in C are not thought to deviate from this model, there is some

evidence (albeit widely ignored in the literature) suggesting that exercised induced elevations in T are not of gonadal origin (Kuopposalmi, 1980; Sutton, Coleman, Casey, & Lazarus, 1973). Furthermore, some studies have shown that T production does not increase at all, but rather increased concentrations during exercise are a result of reduced metabolic clearance from the blood (e.g., Cadoux-Hudson, Few, & Imms, 1985).

Although this mechanism would perhaps be energetically favorable, additional research has revealed contradictory evidence. For example, Cumming et al. (1986) showed that although exercise related increases in T are not likely of gonadal origin, this effect cannot be explained by reduced metabolic clearance alone. The precise mechanism for a non-gonadotrophin source for T production remains unknown. However, it is possible that there are separate mechanisms for T production. This speculation is drawn from the observation that T and C show a complex, asynchronous relationship from before to after warm-up (when exercise is introduced) as evidenced by results from the present study and previous studies, but become synchronous from after warm-up to after competition (when more intense exercise is introduced). Due to the more definitive understandings regarding an adrenal origin for C, it may be that T and C production arise from separate mechanisms with C originating adrenally and T originating from some undetermined source.

There is evidence to suggest that C and T production from the HPG interact. Several studies have shown that C has a suppressing effect on circulating testosterone (e.g., Cumming, Quigley, & Yen, 1983) with specific inhibitory effects at all three levels of the HPG axis (Johnson, Kamilaris, Chrousos, & Gold, 1992). That T and C show synchronous increases during competition, demonstrated in the present study, support



aforementioned findings from Cumming et al. (1986), suggesting that exercise related elevations of T do not originate from the HPG axis. That is, if T production during competition were gonadal, then T elevations during competition would have been inhibited or suppressed due to elevations in C. Additionally, results from the current study showed that although women using OCs during the time of the competition were, on average, lower in levels of salivary T before- and after warm-up and after competition, they demonstrated identical warm-up and competition fluctuations in T as women not using OCs. Given that the primary mechanism of action for most OCs inhibits the release of gonadotrophins (i.e., follicle stimulating hormone, luteinizing hormone) at several levels of the HPG axis (Rivera, Yacobson, & Grimes, 1999), transient elevations in T seen during competition, again, are not likely of gonadal origin.

The asynchronous nature of the changes in C and T levels prior to competition (noted earlier in rejecting an adrenal T origin) also contributes to the issue of exercise related changes in hemoconcentration. Kargotich, Goodman, Keast, and Morton (1998) assert that blood plasma volume undergoes considerable fluctuation based on a number of environmental and physiological factors, including temperature and hydration. Hemoconcentration, fluid shift out of the intravascular space, may increase concentration of other plasma components (e.g., hormones) and has been observed during short duration, high intensity and prolonged aerobic exercise (Kargotich et al., 1998). This presents an issue for serum concentrations of hormones observed during competition because plasma volume changes alone may account for the noted elevations of T and C. However, data from the present study suggest that hemoconcentration cannot account for all of the competition effect. If it did, then change in C and T levels should be

synchronous during warm-up as well as competition, which the results of the present study did not reveal. Additionally, hormones pass from the bloodstream into the interstitial fluid (i.e., fluid inside cells) and then into their target tissues (e.g., muscle cells) (Kargotich et al., 1998). This indicates that concentrating blood volume due to fluid loss will likely be matched by some loss of hormone concentration. Thus, substantial elevations in serum T or C are not likely due solely to hemoconcentration.

Although serum or plasma composition certainly is relevant due to its necessary involvement in distributing hormones to target areas, it may be less relevant in considering concentrations of *salivary* T and C in the present study, as saliva is extravascular. Surprisingly, little is known regarding the transduction of hormones from the blood to the saliva. Despite the common finding that serum and salivary hormone concentrations are often correlated (e.g., Kirschbaum & Hellhammer 1994; Wood, 2008), Stanczyk (2006) warns that it is a misconception to assume salivary levels of T reflect free serum levels. This is due in part to the inability of unconjugated T that is bound to larger molecules in the blood to pass into salivary compartments (Stanczyk, 2006). Further, Cook (2002) showed that at rest, serum and saliva hormone concentrations were linearly related, but with a 20-40 minute delay, but this relationship became less linear during exercise. These concerns, however, do not negate the value of saliva measurement demonstrated by the clear competition elevations of both salivary T and C. Thus, it appears that hormones (e.g., testosterone) move along with the shift in fluids out of the vascular compartment into the interstitial compartment and/or that there is an increase of testosterone secretion into the bloodstream and that some of this increase

subsequently shows up in saliva. Again, the precise timing and mechanism of this process remains largely unknown.

### *Theoretical Implications*

Since T and C each have both physiological and psychological functions it remains uncertain as to whether the elevations are due to an increase in physical exertion, the psychological effects of competition, or some combination of the two. Exploring the individual effect of physical exertion, both team sports and cross-country running involve cardiovascular and endurance components, although running a cross-country race may represent a more consistent effort. Several studies have shown that when the competition is purely muscular strength/resistance based, T does not increase (e.g., powerlifting competition; Panse et al., 2010) or may actually decrease (e.g., strength resistance exercise; Kraemer et al., 2001) during competition. Further, there have been several studies that have demonstrated endocrine patterns in competitions that do not involve a large physical component. Mazur, Booth, and Dabbs (1992) showed that T increased in response to a chess competition. Similarly, Steiner, Barchard, Meana, Hadi, and Gray (2010) showed the same effect among participants competing in a poker competition. Conversely, Doan, Newton, Kwon, and Scheet (2007) showed that C, but not T rose significantly over the course of an 18-round golf competition. In combination these studies suggest that physical exertion is not required to create a competition related elevation in T or C. On the other hand, the psychological experience of competing also may not be a necessary component to create elevations in T or C. Several studies have shown that T and/or C increase in response to non-competitive exercise (e.g., Cumming et al., 1986; Moreira, Arsati, Arsati, da Silva, & de Araújo, 2008). It seems then that

there is reason to assume the rise in T and C during competition in the present study is due to a combination of psychological and physical stress or activation.

A second theoretical discussion with regards to the findings in the present study is to address the question, “What adaptive purpose do T and C serve in competitive behavior?” In essence, there could be some reason why, from an evolutionary psychology perspective, humans (and other animals) developed neuroendocrinological response. Contrary to findings from the current study, Salvador (2012) reported that T and C “have shown mostly contrasting roles and relationships with specific behaviors” (p. 76). Explaining these opposing roles, Salvador (2012) asserted that the general behavioral associations for T are related to aggression, dominance, and competitiveness, whereas C is associated with fearful, stress-induced, and defensive behaviors. Unless one can increase in both dominant and defensive behaviors simultaneously, this traditional understanding of T and C as contradicting may not be wholly applicable in the competition setting. Again, given that both T and C have psychological and physiological causes and effects, it is possible that their roles may consist of an adaptive mixture of these components to optimize functioning competition and reduce conflicting behavioral associations.

Due to the known association between T and dominance, T has received the majority of attention in literature that addresses the adaptive purpose of its elevation in competition from an evolutionary psychology perspective. Two theoretical models have been proposed: the challenge hypothesis (Wingfield, Hengner, Dufty, & Ball, 1990) and the biosocial model of status (Mazur, 1985). The challenge hypothesis asserts that T levels rise during challenges in the social environment that are relevant for reproductive

physiology and behavior (Salvador, 2012). The biosocial model of status makes the same assertion, but in addition, predicts that T concentrations will elevate only for winners, promoting dominant behavior to protect status, whereas T will decrease for losers, promoting submissive behavior (Carré et al., 2011).

Two important interpretations can be made from these models. First, T fluctuations, rather than baseline levels, are more important for understanding competition behavior. Second, these fluctuations are adaptive, promoting aggressive behaviors beneficial to competition and allowing the individual to rapidly adjust to changes in the social environment (Carré et al., 2011). Thus, regardless of the physiological benefits of T, elevations of this hormone may independently represent a socially adaptive response to the status challenge of competition. As a result, competition requires continuous appraisal of the social environment and one's own status in relation to that environment. Salvador (2012) suggested that it is this appraisal or interpretation of the situation during competition, rather than the performance outcomes, that determine the neuroendocrine response. As such, psychological constructs such as outcome expectancy and perceived control can generate adaptive or maladaptive physiological responding during competition.

This hypothesis is important for sport psychologists because it suggests that psychological coping skills may play a valuable role in determining physical functioning during a sporting competition. Furthermore, this notion broadly supports similar theoretical models regarding the effect of perceptions on performance during competition. Specifically, in the challenge versus threat perception theoretical model (Jones et al., 2009) the perception of a task as a challenge or a threat may result in a more

or less adaptive physiological response. Under this theory, understood primarily as operating among athletes in preparation for competition, a positive psychological response is to perceive competition as a challenge, whereas a negative response is to perceive competition as a threat. Subsequently, this perception may lead to differential physiological functioning, in a seemingly self-perpetuating feedback cycle (Jones et al., 2009). Furthermore, it has been hypothesized that the perception of an approaching competition as a challenge or threat is a motivational state that is composed of cognitive, affective, and physiological components that drive engagement in a meaningful event (Blascovich & Mendes, 2000). Previous research provides evidence to support this theory of challenge versus threat states. For example, Jones and Swain (2005) and Jones, Swain, and Hardy (1993) demonstrated that for elite level athletes who perceived performance related psychological experiences (e.g., anxiety) as more positive or facilitative, then these perceptions of anxiety were associated with higher levels of actual performance.

Incorporating models of T and aggressive behavior, a challenge perception may promote dominant behaviors with a rise in T, whereas threat perception may promote submissive behaviors that could result in a drop in T (or theoretically, a stress response that would result in elevated C). Ongoing appraisal during competition may also be impacted by the direction of attention with regard to the interpretation of physical symptoms (e.g., heart rate, muscle fatigue). Individual differences in affect and other personality traits may be an indicator for either maladaptive consequences for the interpretation of physical symptoms (as seen in hypochondriacs) or adaptive consequences (as seen in seasoned professional athletes) (Barsky, 2001; Morgan &

Pollock, 1977). Cognitive factors, such as self-concepts and self-efficacy, may also impact somatic attention creating either a positive or negative response to physical stress (Cioffi, 1991). The interpretation of somatic experiences as negative or positive may not only affect symptom reporting, but also have a significant effect on physical performance (Casto & Lecci, 2012). In general, various cognitive factors such as attention, somatic interpretation and expectancies, and individual differences in physical fitness and affect may play an important role in the experience of physical sensations and the appraisal of a competition environment.

#### *Limitations and Future Directions*

A major limitation of the present study was the limited number of participants. With a small sample size, individual variations in patterns reduced the confidence with which interpretations of generality could be made. Additionally, participants with non-traditional T and/or C patterns may have negated expected effects, particularly with regard to hypothesized pre-competition elevations. Future work in this area will benefit from collecting and continuing to compile larger samples. Furthermore, future work will focus on determining the individual effects of the psychological and physical components in contributing to the competition elevations of T and C. Specifically, to explore the role of physical intensity in contributing to the effect, future studies should look at patterns of T and C for athletes in competitions that do not have a large cardiovascular or strength component (e.g., pistol shooting, archery). Likewise, to explore the role of psychological stress in contributing to the effect, future studies also should look at athletes participating in training or exercise tasks that are non-competitive. Additionally, the role of mental

toughness and other psychological variables in explaining the competition related elevations in T and C require further investigation.

*Conclusion*

Results from the present study provide a basis for discussing features of T and C regarding their physiological origin, interaction in the body, and mechanism of distribution throughout the body. Additionally, results may be interpreted with regard to the adaptive purpose of T and C in competition from an evolutionary and social psychology perspective as well as a cognitive-appraisal framework. Future work will be generated towards parsing out the individual psychological and physiological effects of T and C in competition.



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